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FUEL — ELECTRICITY — MACHINERY — METHODS

EMPIRE BUILDING, PITTSBURGH, PA.

To Educate the Engineer in Industry

JUNE, 1924

Containing the Proceedings of the A.I.&S.E.E.

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DETROIT.

Control of Pressure Gas Producers

By W. P. CHANDLER, JR.
Fuel and Experimental Engineer, Carnegie Steel Company, Duquesne, Pa.

Measurement of Input and Output in Boiler Rooms

By J. M. SPITZGLASS
Engineer, Republic Flow Meters Company, New York, N. Y.

The Prevention of Scale Formation by Boiler Water Conditioning

By R. E. HALL, Physical Chemist, Pittsburgh Experimental Station, U. S. Bureau of Mines; CARL FISCHER, Superintendent of Heat, Light and Power, Mesta Machine Company, Homestead, Pa.; GEORGE SMITH, Chemical Engineer, Hagan Corporation, Pittsburgh, Pa.

The Chapman-Stein Recuperator

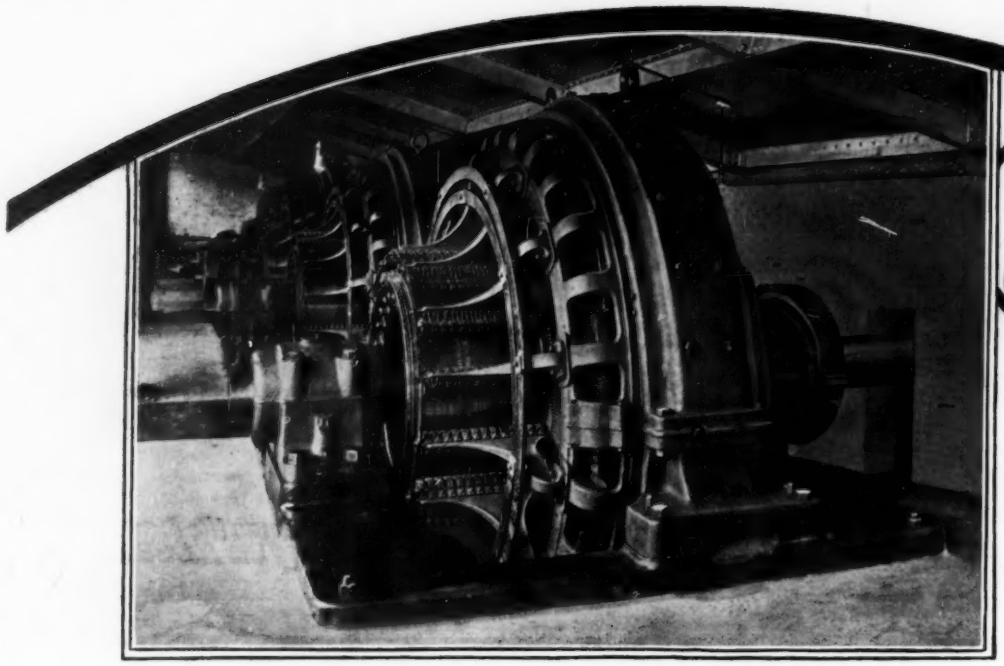
By WM. C. BUELL, JR.
Engineer, The Chapman-Stein Furnace Company, Mt. Vernon, Ohio

The Ljungstrom Air Preheater

By B. G. BROLINSON
Chief Engineer, James Howden & Company of America, Inc., Wellsville, N. Y.

Some Applications of Oxygen to Ferrous Metallurgy

By F. W. DAVIS
Metallurgist, Bureau of Mines, Department of Interior, Washington, D. C.



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IRON AND STEEL ENGINEER

J. F. KELLY, Editor

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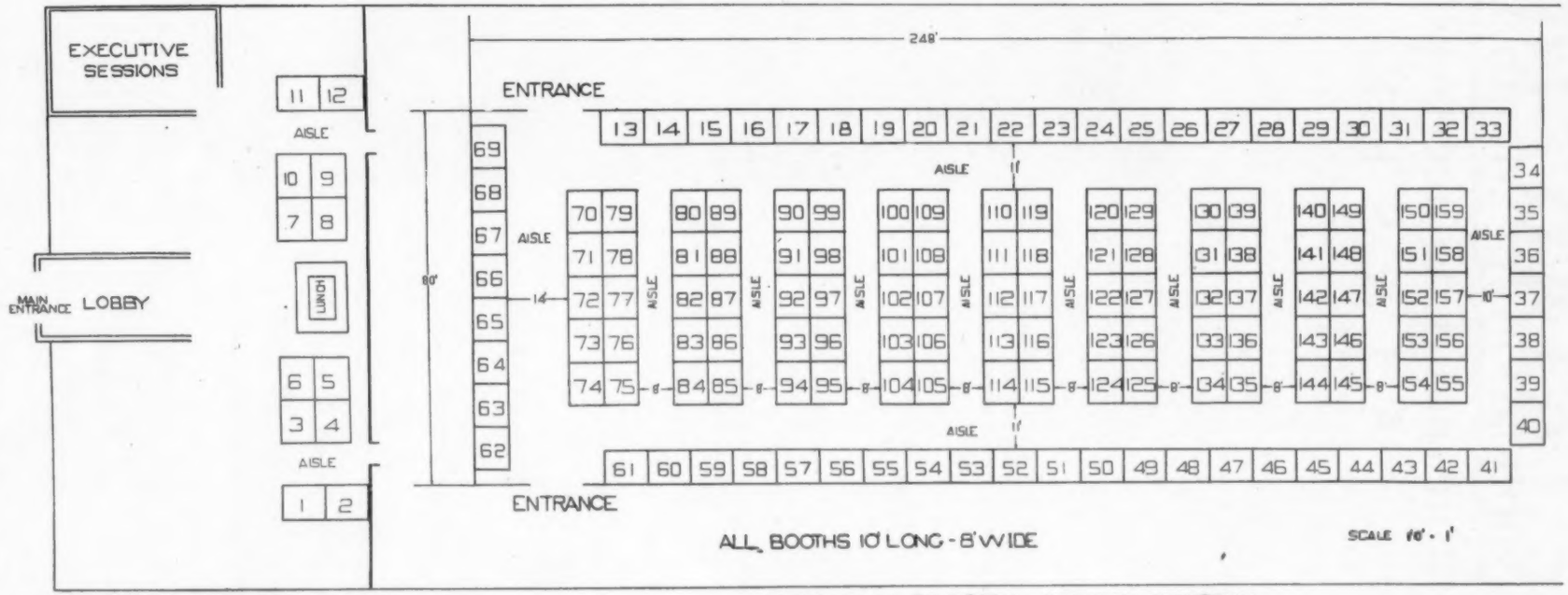

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Application is hereby made to the Combustion Engineering Section for admission to membership:

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County of .....State of.....

State present position, whether Combustion Engineer, Mechanical Engineer, Chief Engineer or Master Mechanic.....

Company..... City..... State.....

State years of experience in steel mill practice .....

.....

State years of experience in steel mill sales.....

.....

References:

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....

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Your name.....*Address* .....

Company .....*City* .....*State* .....

Return this application to W. P. Chandler, Secretary, Combustion Engineering Section, A. I. & S. E. E., 705 Empire Bldg., Pittsburgh, Pa.
Entrance Fee $10.00 Dues $10.00 per Year

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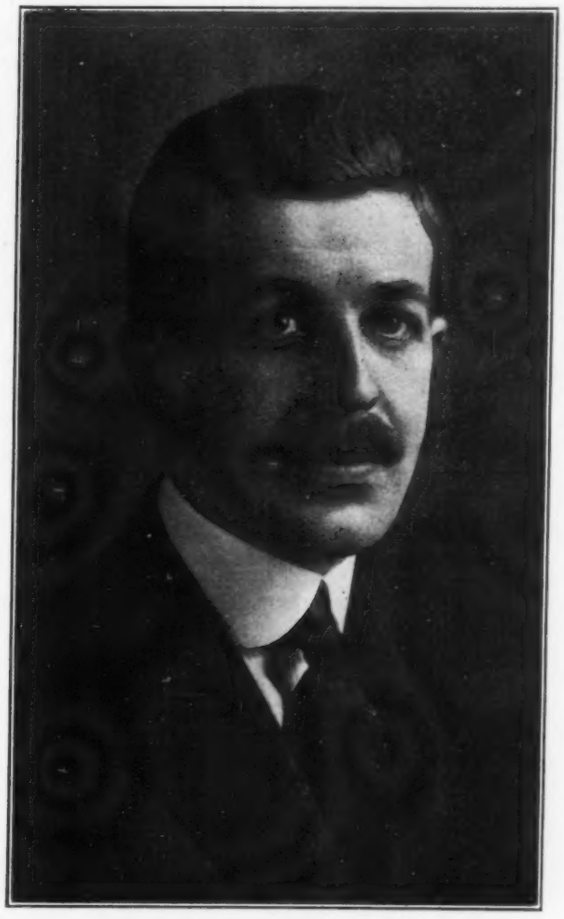
W. P. Chandler, Secretary, Fuel Engr., Cernegie Steel Company, Duquesne, Pa.

EDITORIALS

FUEL SAVINGS CONFERENCE

THIS issue is devoted to the papers and discussions which were presented before the Combustion Engineering Sections of the A. I. & S. E. E. at their first Annual Fuel Savings Conference, held April 2nd and 3rd, 1924.

The fact that a Fuel Savings Conference was held is sufficient evidence that the engineers of the steel industry recognize the increasing importance to the industry of this subject and the necessity of joining



W. P. CHANDLER

Secretary, Combustion Engineering Section A. I. & S. E. E., Fuel Engineer, Carnegie Steel Company, Duquesne, Pa.

forces to better solve the problems arising from the increasing cost and decreasing supply of our available fuels.

You will find if you analyze the papers and the discussion many valuable suggestions for the elimination of fuel waste, and we are quoting one engineer in particular who, through efficient methods and close analysis, managed to effect savings which are remarkable and if duplicated throughout the industry would result in the conservation of millions of tons of coal.

"Coal Losses Due to Standby Steam Requirements and Demands"

G. D. Spackman

This subject is of vital importance and interest to all steel plant engineers as the standby losses, in most cases, are very large and, needless to say, expensive. In steel plant practice we cannot as a rule anticipate the load factor as closely as the central stations, due to numerous causes, such as heating troubles, mill failures and many other common delays. The boiler house as a rule must have steam up for the greatest load which it will have to carry and hence, if great care is not taken, large losses will result.

Many steel plants, due to additional mills being added, have numerous boiler houses scattered all over the plant, which of course increases the chances for standby losses immensely. This was the case at the plant with which I am connected, as there were five different boiler rooms, some of which were more or less connected together. By having a connected system we were able to gradually cut boilers off the line until the present time when we are simply operating one large boiler room, with the help of the waste heat boilers and two or three small H.R.T. boilers when necessary.

These changes made it necessary to carry only four men a turn instead of 36 and fire only 1500 B.H.P. as against 5650 B.H.P. Needless to say the cost of the centralized system was saved in less than two months' time. Better service was also established, as the different loads of the mills tended to equalize into a steadier pull.

Another feature which has been found very successful in cutting down the standby losses is a signal system between the boiler house and the mill engineers. We have such a system in operation at our plant and find it very satisfactory. Five to ten minutes before starting the engine, the engineer will pull a switch which lights a light behind his mill number in the boiler house, likewise when he has finished rolling for any length of time he pulls the switch turning out his light. If a breakdown or anything unusual occurs he will telephone the boiler chief at once, stating how long he will be off. This simple system has saved us considerable in money as well as better steam service and cutting down standby losses. The more closely you keep your boiler house in contact with the places of demand, the more efficient and economical generating station you will have.

Lastly, a department metering system will help to cut down your losses. By studying the different curves from day to day a fair idea of just what will be needed for certain loads can be determined. Big leaks and unusual steam consumptions can be checked up and traced directly to the source. All the steam which we generate is now metered by two master meters and then metered to the different departments. The integrating and recording units of these meters are all located on one panel. Very accurate costs can be obtained as well as many useful and interesting points on mill steam consumption.

MEDIUM AND LOW TEMPERATURE ELECTRIC FURNACES

FOR the last three years the Electric Furnace Committee report dealt mainly with the steel melting or high temperature furnace. It covered very thoroughly the theory and operation and in fact left little or nothing undone. It was therefore decided to report only the improvements in design and in methods of operation that have taken place during the last year, and cover the medium and low temperature as fully as possible, showing present uses and its future possibilities particularly as applying to the iron and steel industry.

The field of the medium and low temperature furnace covers numerous and greatly diversified applications in all field of industrial endeavor. Improvements and refinements in design together with changes in methods of operation have shown marked economy in favor of this particular type of equipment—even in localities where electric power rates are not particularly low. The total connected load of these furnaces has reached formidable figures and these figures are increasing at a rapid rate.

It is desired to fully describe as many present applications as possible, covering the iron and steel and allied industries, in fact, covering the application of the electric heating furnace in all fields.

It is further desired to show savings accomplished in as many different applications as possible, omitting the name of the company, but giving the operating figures and showing just wherein the economy lies. By giving these figures the report will be of great value to any one interested or considering the advisability of an installation, by giving data obtained from actual operation.

The Electric Furnace Committee invites and solicits data from the operating engineers. Your suggestions will also be appreciated. Mail to any of the following: George H. Schaeffer, Carpenter Steel Company, Reading, Pa.; J. A. Seede, Industrial Engineering Department, General Electric Company, Schenectady, N. Y.; Horace Drever, Electric Furnace Construction Company, 1015 Chestnut Street, Philadelphia, Pa.; E. A. Hurme, Steel Mill Section, Westinghouse Electric & Manufacturing Company, East Pittsburgh, Pa.; C. J. Cone, The Hagan Corporation, 1301 Chamber of Commerce Bldg., Pittsburgh, Pa.; E. D. Sibley, Metropolitan Edison Company, Reading, Pa.

MACHINE TOOLS

Without tools he is nothing.
With tools he is all.
—Carlyle, "Sartor Resartus," chapter iv.

LITTLE is known today by the general public, as well as the engineering fraternity, as to who the great tool builders were, and less is known of their lives and work. History takes good care of the soldier, the statesman, the author, the artist, but what is known of Maudslay, Nasmyth, Whitney, the mechanical geniuses who made possible the mechanical wonders which exist today, and whose devices are used daily with little thought of their origin.

The machine tool industry is an industry of vital importance both in times of peace and war, and we may safely write that we owe to this industry the skilled artisans that exist today. More machine tools, more skilled artisans.

Today, like the stone age, each stage of man's progress is marked by an improvement in his tools. Every machine tool designed today is calculated to save labor and increase production.

In order that the members of the A. I. & S. E. E. will be thoroughly informed as to the most modern practices with respect to machine tools, a paper will be presented before the annual convention, September 15th to 20th, 1924, at Pittsburgh.

Your suggestions are invited. Write the A. I. & S. E. E., 706 Empire Building, Pittsburgh, Pa.

OUTINGS

EACH year each section aims to have and has an outing, which is usually participated in by the entire membership. Engineers, usually imbued with the spirit of conservatism, forget at least, the day of the outing, that there are steel mills, and enter into the pastimes provided for them with the heart of the boy who has no cares.

The Philadelphia Section provided for their members this year an outing on the Perkiomen River, where many interesting sporting features were indulged in. One of the most interesting, however, was a two-act comedy, styled "The A. I. & S. E. E. Follies of 1924." This little playlet represented almost a herculean task, some of the members of the cast traveling over 100 miles to attend. The show was a howling success, and the engineers who labored for their brothers' amusement were L. O. Morrow, P. T. Vanderwaart, Siles Boone, Grant Armor, Charles Williams, Norman Farrar, George Ward, Ben Hare, Harry Nichols, C. J. Maloney, W. H. Gledhill and George Pfeffer.

The Pittsburgh Section held their annual outing in the form of a boat excursion and inspection trip as the guests of the Carnegie Steel Company and the National Tube Company.

The plant of the National Tube Company at McKeesport was visited, and the largest by-product plant in the world at Carnegie Steel Company at Clairton, Pa. The members were royally entertained by both companies. The chairmen in charge were J. J. Booth, general arrangements; S. S. Wales, reception; A. C. Cummins, luncheon; E. Friedlaender, admission, and Saul Lavine, entertainment.

The Cleveland District Section will entertain their members at an outing in the form of a lake trip from Cleveland to Cedar Point on June 28th, 1924. The steamer City of Erie has been chartered for the day and will leave promptly from the foot of East Ninth Street at 8 o'clock Eastern standard time. Any visiting member who is in or around Cleveland that day is invited. Boat arrives back at Cleveland at 8 P. M. Fare round trip $1.35. Invitation reads "Bring your kids."

The Birmingham Section entertained their members and friends this year with an outing at the Roebuck Country Club. Golf was the main amusement of the day and the elimination contest found "Jess Adkins and Bill Suppler" at the nineteenth hole. The game was declared a draw. The Birmingham Section exemplifies the spirit of Southern hospitality to the highest degree. Go down, visit them, and find out. The committee in charge were W. B. Connally, J. E. Harrell, L. M. Smith, M. M. Argo and A. L. Freret.

The Chicago Section plans an outing this year which will far surpass anything they have so far attempted. The complete plans will be announced later. Look for "Pete" Williams's usual surprises.

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Fuel Savings Conference

The Combustion Engineering Section of the A. I. & S. E. E. offers to you in this issue the results accomplished at their Fuel Savings Conference, held in Pittsburgh, April 2nd and 3rd, 1924.

You are earnestly urged to read each and every article and the discussion offered by the various engineers who attended the conference, and if you feel that you have any data which will be of interest to the engineers in connection with these subjects please forward your information to the Association's headquarters, and it will appear in the Iron and Steel Engineer.

The titles, authors and names of the engineers who participated in the conference are as follows:

Titles of Papers and Authors

"Control of Pressure Gas Producers," W. P. Chandler, Jr.

"The Chapman-Stein Recuperator," Wm. C. Buell, Jr.

"Some Applications of Oxygen to Ferrous Metallurgy," F. W. Davis.

"The Prevention of Scale Formation by Boiler Water Conditioning," R. E. Hall, Carl Fischer and Geo. W. Smith.

"Measurement of Input and Output in Boiler Rooms," J. M. Spitzglass.

"The Ljungstrom Air Preheater," B. G. Brolinson.

Engineers Participating in the Discussion

W. N. Flanagan, Steam Engineer, Ohio Works, Carnegie Steel Company, Youngstown, Ohio.

H. C. Seibert, Steam Engineer, Bethlehem Steel Company, Bethlehem, Pa.

W. R. Little, Engineer, Bailey Meter Company, Pittsburgh, Pa.

A. G. Witting, Assistant Chief Engineer, Illinois Steel Company, Gary, Ind.

J. B. Crane, Engineer, George T. Ladd Company, Pittsburgh, Pa.

Strickland Kneass, Steam Engineer, Youngstown Sheet & Tube Company, Youngstown, Ohio.

Dr. J. B. Unger, Director of Research, Carnegie Steel Company, Pittsburgh, Pa.

Harrington Emerson, Emerson Engineers, New York, N. Y.

Victor Windette, Engineer, Wellman Seaver Morgan Company, Cleveland, Ohio.

Martin J. Conway, Fuel Engineer, Wheeling Steel Corporation, Steubenville, Ohio.

F. G. Cutler, Chief of Bureau of Steam Engineering, Tennessee Coal, Iron & Railroad Company, Birmingham, Ala.

J. M. Spitzglass, Engineer, Republic Flow Meters Company, New York, N. Y.

W. P. Chandler, Fuel and Experimental Engineer, Carnegie Steel Company, Duquesne, Pa.

Arthur Steed, Steam Engineer, American Rolling Mills Company, Middletown, Ohio.

A. E. Miller, Superintendent Mechanical and Electrical Department, Allegheny Steel Company, Brackenridge, Pa.

A. L. Milton, Steam Engineer, Wheeling Steel Corporation, Wheeling, W. Va.

Carl Smith, Steam Engineer, Inland Steel Company, Indiana Harbor, Ind.

W. Dryssen, Metallurgist, United States Steel Corporation, New York, N. Y.

A. L. Culbertson, Vice President, Chapman Stein Furnace Company, Mt. Vernon, Ohio.

W. D. Brown, Chief Chemist, Carnegie Steel Company, Duquesne, Pa.

G. D. Spackman, Fuel Engineer, Lukens Steel Company, Coatesville, Pa.

T. J. McLaughlin, Assistant Fuel Engineer, Carnegie Steel Company, Duquesne, Pa.

B. R. Shover, Consulting Engineer, Pittsburgh, Pa.

R. S. Shoemaker, Superintendent of Maintenance, American Rolling Mills Company, Middletown, Ohio.

F. E. Leahy, Power Engineer, National Tube Company, Pittsburgh, Pa.

Control of Pressure Gas Producers

By W. P. CHANDLER, JR.*

Introduction.

OF late years fuel saving has become an issue of the greatest importance to the steel industry. The coal bill of the boiler houses is being reduced by the installation of up to date efficient boilers, but a study of the fuel requirements of a steel plant show that twice as much coal is required by the gas producers of an open hearth plant as is used for generating the steam required in rolling the steel. It is evident, therefore, that fuel economy at the gas producers demands close attention.

The following paper was prepared in order to indicate the main factors influencing producer operation, and to suggest means for obtaining the greatest return from a given sized gas producer and from the coal charged. This means gasifying at the greatest rate, so as to obtain the maximum return from the initial investment, and reducing the heat losses in producing the gas, so as to obtain the highest possible efficiency. No comparison is given of the various makes of producers on the market, and the discussion will be limited to the type of producer usually installed in steel mills for furnishing fuel to metallurgical furnaces.

Description of Pressure Gas Producers.

The type of producer most widely used for supplying a gaseous fuel for use in metallurgical furnaces in steel mills is the pressure producer. The producer may be rotated mechanically, or it may be stationary; may be either mechanically or manually poked; and may be equipped with an ash plow, or the ashes may be removed by hand.

The feature determining the type, however, is the means provided for causing a flow of gas through the fuel bed. In pressure producers, the air for combustion is blown into the producer by some means, such as the stream jet aspirating blower, or the turbo-blower. The steam jet blower has the lowest first cost and requires very little attention. However, the turbo-blower is more economical in steam consumption, and with its use the amount of moisture introduced with the air blast may be readily controlled. This last advantage is of prime importance.

Gasification Rate.

The amount of coal that can be gasified in a producer per square foot per hour has increased enormously of late years. Latta, in his treatise on Gas Producers, fixes 10 pounds as good practice, and a few years ago 20 pounds per square foot per hour was more than could be obtained from a well known mechanical producer. However, recent practice has shown that 30 to 50 pounds and even higher are obtainable.

The amount of coal that can be consumed in a producer is dependent, primarily, on the amount of air supplied for combustion. In a great many existing producer installations, equipped with steam jet blowers, the capacity of the blower limits the gasification of coal to about 25 pounds of coal per square foot per hour or 2,000 pounds per hour for a 10-ft. diameter producer. To obtain the much higher rates possible, provision should be made for furnishing the requisite amount of blast.

Gasification Efficiency.

The gas producer process consists of distilling off the volatile matter in the coal in the upper zone of the producer, and converting the fixed carbon in the coke, formed by the distillation, into combustible gases by the action of air and water vapor.

Part of the heat liberated in the producer, by the oxidation of the carbon to carbon dioxide and carbon monoxide, is used in distilling the volatile ingredients of the coal, and bringing the coke and ash to the combustion zone temperature. The remainder raises the temperature of the gases to that of the producer outlet, or is absorbed by the decomposition of the water vapor present in the blast. The function of the producer is to convert coal into combustible gas, and the operation which produces from a given coal the largest amount of calorific heat in the gas is the most efficient.

In the following discussion, the calorific heat of the soot, tar and hydrocarbon gases present in the producer gas will not be considered, since these are distillation products, and are dependent on the quality of the coal used. The remaining constituents of the gas are the result of the reactions between air, water vapor and carbon, and for maximum efficiency, the inert gases, carbon dioxide and nitrogen, should be held at a low point.

The two main factors, which govern the percentages of combustible and inert constituents in a producer gas, are time of contact between the gas and the incandescent carbon, and the temperature of the combustion zone. These facts have been very well presented in Bulletin No. 7 of the Bureau of Mines, by Clement, Adams and Haskins. They point out, that with ample time, 1800 deg. F. is sufficient to completely transform carbon dioxide in the presence of incandescent coke into carbon monoxide, and that water vapor under similar conditions will be completely changed to hydrogen and carbon monoxide at 2000 deg. F.

In regular producer operation, the gases pass through the combustion zone so rapidly, that only a small percentage of the time required for complete reactions at such temperatures is available.

However, the time element may be increased by maintaining a fuel bed as thick as is consistent with the method of agitation provided, and as homogeneous as possible. The depth of bed can be held within the desired limits by controlling the amount of coal charged. The homogeneity of the bed depends on the size of coal used, and the regularity of the charging and agitation. Manually charged producers give very good results when proper care is used, but a good mechanical feed should produce the same results more readily. Excessive amounts of large lumps and fines in the coal charged tend to decrease the homogeneity of the bed, and allow channelling, with a consequent shortening of the time of contact

*Fuel and Experimental Engineer, Carnegie Steel Company, Duquesne, Pa.

between gases and incandescent carbon. The fines have another detrimental effect due to their relatively high sulphur content, but this will be mentioned later in the discussion.

The rate at which the inert gases will be changed to combustible gases is increased with an increasing temperature. While investigations have shown that, with ample time of contact, temperatures of 1800 deg. to 2000 deg. F. are sufficient for complete transformation, the temperature of the combustion zone of producers should be greater, in order to overcome the lack of time available, while the gases are passing through the combustion zone.

In practice, the lowest amounts of inert gases are obtained with the hottest temperature in the combustion zone; however, calculations have shown that no gain in efficiency is obtained by decreasing the carbon dioxide content below 2 per cent. An increase in gasification efficiency, if the fuel bed is in the proper condition, therefore means an increase in the combustion zone temperature.

Fusibility of Ash.

The principal factor operating against a high combustion zone temperature is the fusibility of the ash from the coal used. No producer will give satisfactory results if excessive clinkers are formed, so the combustion temperature must be maintained below the point of clinker formation.

The ash in the coal from different parts of the country have widely varying softening temperatures, and Table No. 1 has been prepared to show this variation and to indicate the temperatures, below which the combustion zone should be maintained for a given coal. The values shown are averages of determinations of the Bureau of Mines given in their Bulletin No. 209.

An inspection of the table will readily show the effect of the sulphur content of a coal from a given

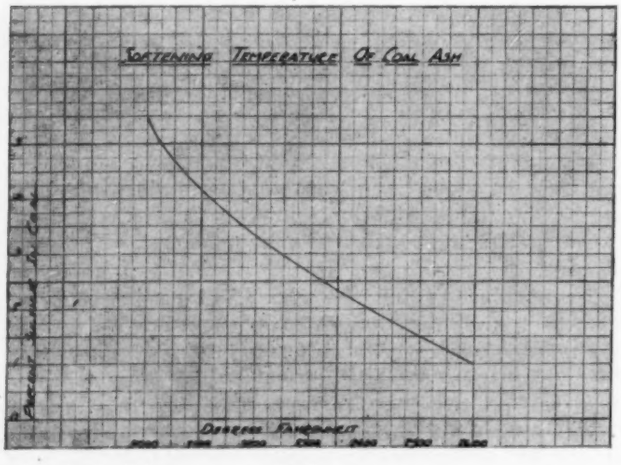


FIG. 1.

seam on the softening temperature of the ash. To illustrate this point, a curve was plotted in Fig. 1 for an Ohio coal, in which the change in the softening temperature of the ash is given for a changing sulphur content. The sulphur content of most coals can be divided between that combining with iron as pyrites, and that organically combined. For any given coal, the percentage of sulphur organically combined is nearly constant, and the varying sulphur contents shown by different analyses depends almost entirely on different pyritic contents. This is shown quite clearly by Table No. 2. In this table, four samples of Pittsburgh vein coal are given; the first three samples from different mines and the last two from the same mine.

TABLE NO. I — FUSIBILITY OF COAL ASH

State	District or Bed	Softening Temp. of Ash °F.	Analysis of Dry Coal % Ash	% Sulphur
1. Alabama	Mary Lee (Big)	2830	9.90	.74
	Nickel Plate	2620	4.73	.75
	Black Creek	2560	2.73	.82
2. Indiana	Clinton	2280	8.50	1.26
	Clinton	1980	10.49	3.65
3. Kentucky	Elkhorn	2500	4.02	.71
	Western	2010	10.82	3.94
4. Ohio	Freeport	2200	7.42	1.99
	Freeport	2150	8.23	3.03
	Kittanning	2600	11.13	.72
	Kittanning	2510	6.31	1.70
	Kittanning	2350	8.09	2.34
	Kittanning	2090	8.33	4.10
	Kittanning	2010	12.52	5.33
5. Penna.	Pittsburgh	2430	6.38	1.15
	Pittsburgh	2100	7.24	2.19
	Freeport	2470	7.25	1.52
	Freeport	2270	7.52	2.35
	Kittanning	3010	5.37	.68
	Kittanning	2210	7.36	2.26
6. West Virginia	Fayette Co. Sewell	2470	3.82	.89
	McDowell Co. Pocahontas ...	2330	5.24	.64
	Mercer Co. Pocahontas ...	2580	4.06	.53
	Marion Co. Pittsburgh	2230	6.10	.81

TABLE NO II

Mine No.	Per Cent Pyritic Sulphur	Per Cent Organic Sulphur	Per Cent Total Sulphur
1	.22	.77	.99
2	.48	.79	1.27
3	.29	.73	1.02
4	.14	.77	.91

TABLE NO. III

		Per cent of Total Coal	Analysis of Portion % Ash	% Sulphur
On	1¼" Mesh	50.0	7.70	.99
	½" "	18.12	7.90	1.08
	⅛" "	18.45	7.75	1.44
	20" "	6.73	8.05	1.38
	60" "	4.22	9.40	1.54
	100" "	.74	10.25	1.71
Thru	100" "	1.74	13.20	1.78

Further investigation has shown that the fines in run-of-mine coal contain a higher percentage of sulphur than the lumps. This is indicated by analysis of the partitions of a sieve test, made on a barge of run-of-mine coal from the Pittsburgh vein. The results are given in Table No. 3.

The high sulphur content of the fines clearly indicates the increased percentage of pyrites contained. A thorough screening of the coal before it is charged into the producer will eliminate a considerable part of the pyrites, and allow a higher combustion zone temperature to be maintained without excessive clinker trouble.

Control of Combustion Zone Temperature.

The temperature of the combustion zone is controlled by the amount of water vapor dissociated, or is dependent on the amount of water vapor carried into the producer by the blast. The temperature of the blast, which is saturated with water vapor and usually contains a small additional amount in suspension, furnishes a means of controlling the amount of watervapor entering the producer. From this it is seen that the temperature of the combustion zone, and with it, the gasification efficiency may be controlled by varying the saturation temperature of the air blast.

Bone and Wheeler, in their classic study of the gas producer, called attention to the effect produced by varying the amount of water vapor introduced with the blast, and recent investigations conducted on modern producers have shown the direct relation existing between the blast saturation temperature and the quality of gas made. Table No. 4 shows a comparison of the gas made with different amounts of water vapor in the blast per pound of coal gasified. In determining the values given, the results of a number of tests have been averaged.

TABLE NO. IV

Pounds of moisture in blast per pound of coal gasified..		0.37	0.30	0.20	0.18
Analysis of gas: CO	%....	22.6	25.8	28.2	30.3
CH_4	%....	3.4	3.0	3.3	3.3
C_2H_4	%....	.5	.4	.4	.4
H_2	%....	12.4	13.2	10.3	9.7
CO_2	%....	8.0	4.6	3.2	2.2
N_2	%....	53.1	53.0	54.6	54.1
Net heating value.....		145.1	152.5	155.0	160.1

It is quite probable that certain coals, such as the Clinton coal of Indiana, which have low ash fusion temperatures, could not be gasified in a producer with as low a moisture content of the blast as indicated by the last two analyses, namely .20 and .18 pounds of moisture per pound of coal gasified. However, a producer using different grades of coal should be equipped to handle each grade in the most economical manner. It is very important for the best operation, that means be provided of varying the amount of moisture in the blast. This is impossible with the steam jet blower, and consequently, a producer equipped with such means of providing blast must be designed for the worst coal to be met with in practice. If good coal becomes available for use in such a producer, the best results cannot be obtained, due to the limit of the original design.

It is for this reason that the turbo-blower can be adapted so successfully to producer practice. The exhaust steam from the turbine may be piped directly into the blast pipe, or part may be wasted to the atmosphere; or, if the whole amount of exhaust steam is insufficient, a secondary supply of live steam may be provided to increase the moisture in the blast to any desired point.

Characteristic curves for both steam jet blower and turbo-blower are shown in Figs. 2 and 3 respectively. The size of the steam jet blower, for which the curves are given, is that usually installed in connection with a 10-ft. producer. The steam required per 1,000 cu. ft. of air blown, for the jet blower is merely double that required by the turbo-blower. If no more moisture is required by the blast than that

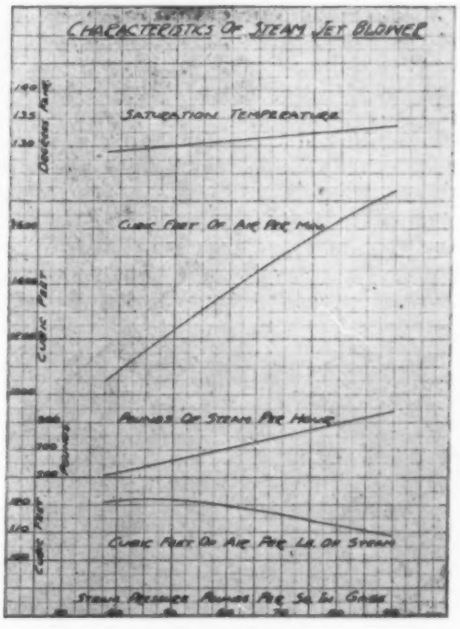

Characteristics of Steam Jet Blower
Saturation Temperature
Cubic Feet of Air per Min.
Pounds of Steam per Hour
Cubic Feet of Air per Lb. of Steam
Steam Pressure Pounds per Sq. In. Gauge

FIG. 2.

found in the turbine exhaust, a saving of 50 per cent in the steam consumption of the producer will be effected.

From Fig. 3 it will be seen that the saturation temperature of the blast from the steam jet blower varies through the narrow range from 129 deg. to 133 deg. F. The moisture contained at this temperature is considerably more than that required by good grades of Eastern gas coal, and the use of a jet blower with such coal means a constant loss in efficiency. With the turbo-blower, any desired saturation temperature may be obtained, and the various fuels used in gas producers can each be consumed in the proper manner.

Producer Operation.

The following test was conducted on a mechanically poked producer of 10 feet diameter, equipped with

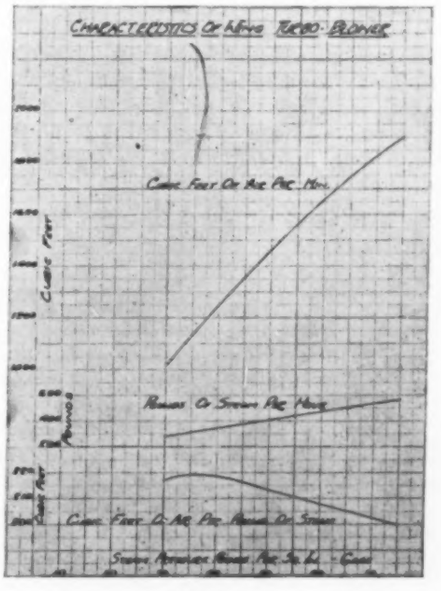

Characteristics of Mine Turbo-Blower
Cubic Feet of Air per Min.
Pounds of Steam per Hour
Cubic Feet of Air per Pound of Steam

FIG. 3.

a turbo-blower. The test covered a period of 72 hours and the main observations for a period of 24 hours are shown on a log sheet given in Fig. 4. Throughout the test, the temperature of the blast was maintained at approximately 110 deg. F. This resulted in the production of gas having an average carbon dioxide content of 3.2 per cent. The minimum value obtained was 1.8 per cent and the maximum, obtained immediately following a fire cleaning period, was 6 per cent.

The builders rating for this producer was 2,000 pounds of coal per hour, but with the steam jet air

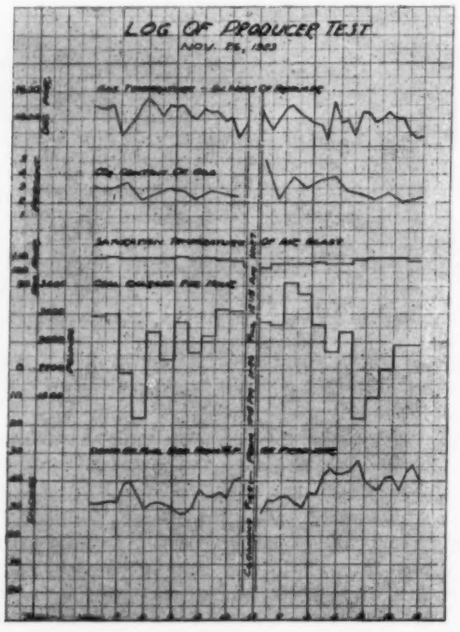


FIG. 4.

blower, which was originally installed, 1600 to 1800 pounds per hour was the limit obtained. During the test, an average for the whole 72 hours, including fire cleaning periods, was over 2400 pounds per hour, with periods of several hours duration averaging 3000 pounds per hour.

The coal used in the producer during the test was bituminous coal from the Pittsburgh vein, crushed to a three inch size and cleaned by passing over one-half inch screens. The average sulphur content was nine-tenths of one per cent, and no trouble was experienced from clinker formation.

The results obtained during the test are shown in Table No. 5.

TABLE NO. V

Date of test		Nov. 26-28, 1923
Duration of test	Hrs.	72
Diameter of producer	Ft.	10
Source of air blast		Turbo-Blower
Atmospheric Conditions:		
Barometer	"Hg	29.33
Atmospheric Temperature:		
Dry bulb	°F	62.7
Wet bulb	°F	
Coal:		
Kind of coal		Pittsburgh Vein
Size of coal	In.	3
Proximate analysis:		
Volatile matter	%	34.95
Fixed carbon	%	57.41
Ash	%	5.68
Moisture	%	1.96
Heating value (from Ultimate Analysis)	B.t.u.	13,963
Ultimate analysis:		
Carbon	%	78.40
H_2	%	5.20
Ash	%	5.67
N_2	%	1.54
O_2	%	8.29
Sul.	%	.90
Height of fuel bed above blower hood	In.	35.3
Height of fuel bed from top of producer	"	45.3
Total dry coal consumed	Lbs.	177,617
Charged	"	174,779
Dry coal consumed per hr.	"	2466.9
Charged per hr.	"	2427.5
Wet coal charged per hr.	"	2476.0
Dry coal consumed per hr. per Sq. Ft. producing area	"	31.4
Ash:		
Combustible in ashes	%	12.0
Ash in ashes	%	88.0
Total carbon per lb. dry coal	Lbs.	.7840
Carbon lost in ashes per lb. dry coal	"	.00773
Carbon lost in soot and tar per lb. dry coal	"	.03853
Total carbon lost per lb. dry coal	"	.04626
Total carbon lost per lb. dry coal	%	5.90
Air:		
Air blown per lb. dry coal consumed	Cu. Ft.	45.25
Air blown per lb. dry coal consumed	Lbs.	3.4546
Air blown per minute	Cu. Ft.	1860.5
Air blown per minute	Lbs.	142.0
Air blast pressure	"H_2O	9.08
Moisture Conditions:		
Saturation temperature of blast	°F	108.7
Ibs. moisture per lb. air blown	Lbs.	.05764
Ibs. moisture per lb. dry coal consumed	"	.19912
Lbs. moisture dissociated per lb. dry coal consumed	"	.18030
Gas:		
CO_2	%	3.18
C_2H_4	%	.36
CO	%	28.17
CH_4	%	3.35
H_2	%	10.35
N_2	%	54.59
Net calorific value per Cu. Ft. (62°-30")	B.t.u.	154.9
Gas pressure	"H_2O	1.78
Cu. ft. gas per lb. dry coal consumed	Cu. Ft.	65.57
Average temperature in producer neck	°F	1443

Summary.

The large amounts of coal consumed in gas producers, in steel mills, requires that equipment be installed which will enable the operator to exercise the same careful control of operation, which is expected at present in boiler houses.

Care must be exercised to see that the charging is as regular as the type of equipment will permit, and that the ashes are removed without excessive breaking up of the fuel bed, or excessive loss of unconsumed carbon.

A gas producer can be intelligently controlled only when the blast temperature is known, and means are provided for altering this temperature, so as to provide the amount of moisture demanded by the character of the coal being used. Such a requirement can be met only by a separate supply of air and mois-

ture, such as is available when turbo-blowers are used, and auxiliary means provided for wasting part of the exhaust steam, or furnishing additional amounts of live steam as conditions demand.

Experience has shown that the steam jet blower, which has a maximum efficiency for only one grade of coal, is not sufficiently flexible in its operation to meet the various grades of coal usually handled by gas producers; and, that maximum efficiency can be obtained only through the separate control of air and moisture available from the installation of turbo-blowers.

DISCUSSION

T. J. McLoughlin: In his paper Mr. Chandler has very ably stated the factors in producer practice, by the control of which economies may be effected. With the decreasing availability of natural gas as a metallurgical fuel and the ever increasing cost of coal, the importance of fuel economies cannot be exaggerated.

The principal application of producer gas in the steel industry is in open hearth practice, more than 50 per cent of the ingot tonnage being made in producer gas fired furnaces, and it is in this field that the greatest saving can be accomplished. More than 7,000,000 tons of coal are annually used in the steel plants of the United States for the production of fuel gas. The economies are affected in two ways: First, by the production of a gas having a low percentage of non-combustibles and a high calorific value and second, the production of such gas at a greatly accelerated rate, thus making available at all times, and at a low cost, a quantity of gas sufficient to insure a maximum output.

In the design of producers, or the adaptation of existing equipment to the accelerated rate of gasification, a few changes in the standards of design decrease the operating difficulties. Some of these difficulties are:

Blast Distribution.

The blast hood should be designed for rates of blowing up to at least 3,000 C.F.M., and should distribute the blast evenly over the producer area, so that the static pressure against which the blower is required to deliver is as low as possible. It should be so located that it will not be injured by lowering the combustion zone.

Top Temperature.

Since in open hearth practice without waste heat boilers in which both gas and air are regenerated, sensible heat in the producer gas is of no value whatever, the lowest gas temperature consistent with efficient producer practice should be maintained. When driving at high rates, 35-45 pounds of coal per sq. ft. of producer area per hour, it is difficult with hand feed to maintain a green coal zone of sufficient depth and homogeneity to keep the gas at a low temperature and to keep the producer top cool. Even mechanical feeds, by reason of the maintenance of such a homogeneous green coal zone of constant depth, are conducive to the delivery of gas of uniform quality, to long life of expensive top casting and to low losses in radiation and cooling water.

Blowers.

In the use of turbo-blowers the question of lubrication is very important, since this apparatus usually operates in a dust laden atmosphere and with very little mechanical attention. With turbo-blowers it is necessary to have some means of closing the blast line to the producers, so that in event of stoppage in the steam supply to the turbine the producer gas will not back up through the blast line and ignite (being at high temperature) in the fan casing, thus causing considerable damage to the fan. For safety, it is also advisable to have some type of overspeed governor on the fan, so that if the valve in the blast line is closed and the static head removed, while steam is still being admitted to the turbine, it will not run away.

Cleaning.

In the manual cleaning of producers driven at a widely varying rate, considerable care must be exercised to remove only enough ash: Any excess ash removal lowers the combustion zone and endangers the blast hood, while the removal of insufficient ash causes an excessively high fire.

Control.

The turbo-driven producer lends itself very readily to automatic control. The maintenance of constant gas pressure at the source of combustion is a distinct advantage and can readily be effected by controlling the steam pressure at the turbine by means of the gas pressure at the furnace in which the producer gas is used.

A. G. Witting: There is one point on which Mr. Chandler didn't lay stress and which offers one of the most important reasons why a steam jet blower is not efficient. In a set of three or more producers to an open hearth furnace not one of them has the same internal pressure as any of the others, at least with the ordinary type of producers where the ash is removed by hand. One producer has just been cleaned and another one is just about to be cleaned; the thickness of the combined ash and fuel bed is much less in the one than in the other case with the result that the resistance offered in the bed may vary a couple of inches, a variation that will most decidedly affect the volume of air introduced by the blower per pound of steam. If the resistance at the blower is more than 3 inches of water, the steam jet will not function as a blower. Consequently, the rate of gasification is different for each one of the producers, and the producer with the thinnest fuel bed and least suited for good gasification may be doing the heaviest work.

With the turbo-blowers the effect of the internal resistance is small, and it ought not to be difficult to adjust the blowers so that the gasification is approximately equal in all the producers or, better still, in direct proportion to the thickness of the fuel bed. Therefore you should be able to produce a gas of higher quality with turbo-blowers.

I might further point out that with a steam jet blower the variation of air introduced per pound of steam, if we disregard the effect of the internal pressure, is not proportional to the steam pressure. Each type of nozzle has its own curve with a maximum at a certain pressure, but the curve is never a straight line and drops suddenly to nothing when the pressure is reduced below a certain value, laying between 10 and 20 pounds, depending on the design. Accordingly, the possibility of regulating the rate of gasification is much smaller than what should be the case with turbo-blowers.

A. L. Culbertson: In regard to the turbo blower: I believe we are all agreed that it is a very good thing if properly built and properly operated, especially if the resistance to be overcome is excessively high. Nearly always when trouble is encountered with the turbo blower or with fan blowers where steam is admitted, it is found that the operator has a little bit more to do in the correct operation of this equipment than his intelligence will permit. We wish to put ourselves on record absolutely as in favor of turbo blowers and hope that the type of producer operator will soon permit its extensive use.

However, in speaking of blowers, we believe it will be of interest to say a few words about the steam jet blowers. The steam jet blower is the simplest thing possible and if properly designed, proves a very good piece of equipment to be used where little attention can be given to the education of the gas maker in the use of his equipment.

Some years ago we ran a number of tests on steam jet blowers and found that by proper design and employing six stages we had a blower which operated efficiently up to about six inches of water pressure. This is much higher than the ordinary single stage steam jet blower which will stop blowing air when working against a back pressure of about three inches of water. Every single stage steam jet blower should have been thrown away years ago.

The statement was made that the steam jet blower uses twice as much steam as the turbo blower. This may be true in the case of a single stage blower but it is not true when using an efficient five or six stage blower. The speaker ran several tests in England on a producer at the Shelton Iron and Steel Company at Stoke-on-Trent. This producer was a Kerpeley equipped with a Chapman Floating Agitator. During this test the amount of steam used per pound of coal gasified was twenty-eight hundredths of one pound, and we believe that it could not have been bettered any by the use of a turbo blower. Mr. Chandler stated that 25 pounds of coal per square foot was about all that could be obtained using a steam jet blower. At the above plant in ordinary operation 48 pounds per square foot was obtained continually. Shortly thereafter the Frodingham Iron and Steel Company at Frodingham, England, reported that with similar equipment they were running continually at the gasification rate of 57 pounds per square foot. In both the above cases a steam jet blower, the same one already mentioned, utilizing five stages, was employed.

Ordinary pressures obtained in blower casings which are the summation of the gas pressure, resistance of the bed and resistance of the tuyere hood should not be much more than three or four inches of water pressure. An efficient steam blower which will work up to six inches of back pressure, giving a constant or nearly so, ratio of steam and air at all pressures, is therefore able to overcome these resistances and operate satisfactorily.

The condition of the steam available is of great importance. Wet steam is not so important in the case of the turbo blower as it is in the steam jet blower. When utilizing steam jet blowers all condensation due to wet steam is charged against the blower itself and generally never gets into the fire bed.

As producer manufacturers we are in favor of turbo blowers where conditions favor them, but before furnishing this equipment we make it a point to visit any customer's gas house and get acquainted with the personnel of his operating force, making recommendations therefrom.

We believe this an opportune time to go on record as against the purchase of gas producer equipment by anybody on the basis of a capacity guarantee expressed in terms of pounds of coal gasified per hour. In the ordinary purchase of producer equipment this point is nearly always written in by the purchaser. It is an entirely misleading point and one which has led to much dissatisfaction for both parties. It is seldom true that a producer operates most efficiently at high rates of gasification. Neither is it possible to obtain the same high rate of gasification with all coals, nor is it possible to obtain the same rate of gasification with any given coal for all grades, such as run of mine, screened nut, slack, etc. We believe that more confidence would be created between gas producer manufacturers and their customers and more satisfaction evidenced with all equipment if this point were gone into more carefully by both parties and less extravagant statements as to performance expected. More attention should be paid to the operation with regard to the average efficiency that can be obtained both in gasification and operation problems. Also more stress should be placed upon whether the machine or the gas maker makes the gas.

A. G. Witting: In this discussion of the gas producer problem I would like to make a digression from the subject proper, how to get the best efficiency from existing conditions, and indulge in a dream about what will 10 years from now be considered a good producer system for open hearth furnaces.

I don't intend to take up any time with details of producer design or operation; only draw a few rough outlines.

The present deficient fuel efficiency can be attributed particularly to two causes (among several others):

1. Irregular gasification due to the continuously changing capacity of the furnace for absorbing heat, resulting in a widely variable quantity and quality of the gas.

2. Indiscriminately changing ratio between gas and air for combustion due to the independent regulation by hand of the gas and the air supply, resulting in a loss of heat either from incomplete combustion or from too large a surplus of air.

This deficiency can be overcome in the following way:

1. The gas to an open hearth plant will be supplied from a central gas house where a sufficient number of producers are grouped that discharge the gas into a large common main from which the various furnaces draw the amount of gas actually needed. Thus the producers can be operated independent of the furnaces at a uniform rate under the complete control of the gas house force, insuring a gas of uniform and consequently better quality and a rate of gasification corresponding closely to the consumption at the furnaces.

2. To prevent losses from soot deposit and the premature decomposition of the tarry vapors, the gas will from the producer house pass through a scrubber plant where the gas is cooled and cleaned and the ammonia and tar recovered. This arrangement will supposedly pay for the more elaborate installation.

3. The gas leaving the scrubbers is devoid of luminant constituents and consequently valueless as

an open hearth fuel. It must be conditioned by the addition of a hydrocarbon compound, but to accomplish this the gas must be reheated to a temperature of around 300-400 deg. F.

4. Between the scrubbers and the reheater a gas holder of moderate size should be located; in this manner the gas house is made independent of any temporary variations in the gas demand at the furnaces.

5. The reheater is preferably a heat exchanger in which the hot gases from the producers are made to give off part of their heat which is absorbed by the cleaned gas. In this way the size of the scrubbers and their water consumption is decreased. The heat exchanger could possibly be built on the lines of the air preheater we just have heard described.

6. The reheated gas is conditioned by the addition of a luminant. The only hydrocarbon that should be considered is naphthalene which will not dissociate except in the flame. It will be gasified by melting it to a liquid (from the heat in the gas) and sprayed into the main or letting it drop by gravity into the gas main. It will probably not take over one pound of naphthalene for 2,000 cu. ft. of gas.

7. It might be found more economical to use coke instead of coal at the producers in which case it might be possible to dispense with the scrubbers and preheater.

8. The reconditioned heated gas passes into the gas main common for all furnaces, which draw their required gas supply by means of steam driven positive volume blowers. By regulation of the speed the melter will get the proper amount of gas forced by the blower at whatever average pressure is found most desirable through the checkers and through the port or burner into the furnace.

9. The air is also delivered to the furnace through the checkers by a similar blower which by a pressure control apparatus is connected to the gas blower so that it will at all times run at a proportional speed. The ratio of air to the gas will then remain constant, insuring a proper combustion with maximum of efficiency. By this arrangement the melter cannot use gas for cooling the furnace nor turn on extra air in either manner transferring heat over to a waste heat boiler, at best, or to the stack. There will not be more fuel consumed than what the furnace can absorb.

10. With both air and gas under a perfect pressure control, it would probably be found desirable to use some kind of a burner, particularly if the gas is produced with oxygen. In such a case, undoubtedly the principle of a partial premix will be employed, whereby the temperature of combustion will be raised and consequently the ratio of radiation increased permitting a decrease in the amount of naphhtalene for conditioning the gas.

There may be nothing original in this idea, except perhaps that I stand rather lonesome, although not entirely alone, with regard to the importance of naphthalene. Otherwise all the rest has either been tried or at least talked about. But the combination as outlined here might not in its entirety have been advocated, involving as it does some radical changes in design which practically forbid its application to already existing open hearth plants. But we will probably live to see such a combination installed sooner or later in connection with a new open hearth installation. Half-measures will carry us forward but will not land us at the goal.

Victor Windett: Mr. Chandler's interesting paper brings to our attention the importance of the gas producer department of a plant and its relative magnitude as compared with the steam plant. His presentation of the need for suitable control of a gas producer leaves but little more to be said.

The conclusions summarizing the studies in Bulletin 7 of the Bureau of Mines, referred to by Mr. Chandler may be stated thus:

A high gasification rate accompanied by high CO and low CO_2 content of the gas is dependent on high fuel zone temperature and a small amount of steam in the blast.

The work on which this was based was passing a stream of air through a heated glass tube filled with solid fuel. In such an experiment the rate of gasification will be slowed down by an insulating covering of more or less porous ash appearing on the fuel surfaces as the carbon is oxidized, rendering the contact between the gas and fuel less free.

In actual producer operation, such a condition was early sought to be overcome by recourse to hand working of the fire with hand barring. This involved hard manual labor, irregular gas yield both in quantity and quality and loss of coal by the barring pushing coke down in the ash zone.

In 1897 W. B. Hughes introduced the mechanical poker and overcoming largely the objections to hand poking raised the gasification rate in his producers to upwards of 25 lbs. per square foot of horizontal section per hour. Though the poker does not penetrate through the combustion zone its influence is exerted through the entire depth of the fuel. In this way the formerly accepted deep fuel zone is unnecessary.

The latest type of full mechanical producer, with improved poker design and action, shows a further advance in gas production, and with but moderate gas temperatures.

The gas producer of today must satisfy Mr. Chandler's demand of control in its various functions and be able to gasify coals of a wide range of physical and chemical characteristics and at a high rate of working in order to keep the cost of gas at a low figure, and susceptible of quick response to demands for large variations in the amount of gas delivered.

It has been found that these conditions are met with the use of the following features of design and operation:

First: A mechanical coal feed continuously delivering coal in relatively small quantities per unit of fuel bed surface, and immediately controllable as to quantity of coal fed.

Second: A continually oscillating mechanical poker maintaining a level fuel zone and thoroughly preparing and keeping the fuel in proper condition for rapid oxidation.

Third: An analogous working of the ash zone to secure a uniform and free flow of the air blast to the fuel, which is obtained by an intermittent or periodic twisting of the ashes below the fire.

Fourth: A continuous descent of ashes down in the ash pan from which they are removed by a plow adjustable to the varying rate of ash formation.

Fifth: The use of a turbo blower whereby the control of the air and steam of the blast is entirely separate one from the other. In this way it is ordinary practice to work within a limit of 2 deg. F. for the

saturation temperature of the blast, and keep substantially at the critical point of clinker formation. Depending on the characteristics of the ash, producer operation has been secured on as low as a quarter of a pound of steam per pound of coal gasified.

Sixth: The combination of these features has eliminated clinker trouble, breaking down and cleaning fires, and a gradual decrease in gasification quantity and quality as the time draws near for cleaning fires and ash removal in the old style of producers. In regard to "breaking down" of the fire a plant reports in a personal communication the following operation with semi-mechanical producers:

GAS ANALYSIS

	Gas during cleaning period	One hour later
CO	4.8	24.6
CH_4	4.5	2.7
C_2H_4	0.2	0.4
H_2	8.1	12.6
CO_2	15.2	6.2
O_2	0.8	0.3
N_2	66.4	53.2
Net B.t.u. ...	81.6	144.3

In the place of those disadvantages accompanied by low gasification rates and necessarily large producer installations, it is now possible to accept a gasification rate of 50 lbs. per square foot per hour for continuous operation and delivery of a gas of substantially constant quality, using mine run gas coal passing through a 4-in. ring retaining the "fines". The following data referring to recent operation of mechanical producers shows actual current practice and not necessarily maximum or minimum rates actually obtained in operation:

Gas coal from	W. Va.	Pa.	Ind.	Ill.
Minimum gasification per sq. ft. per hour	17.3 lbs.	33.1 lbs.	28.2 lbs.	44.5 lbs.
Maximum gasification per sq. ft. per hour	68.6 lbs.	44.5 lbs.	69.3 lbs.	48.5 lbs.
Minimum gas temperature	740°F.	1300°F.	960°F.	1090°F.
Maximum gas temperature	1650°F.	1450°F.	1200°F.	1160°F.
Steam per lb. of coal	0.26 to 0.37 lb.	0.22 to 0.37 lb.	0.34 to 0.37 lb.	0.36
Variation in CO_2	3.2%	2.5%	1.4%	0.4%
Variation in B.t.u.	20.7	16.5	6.8	5.9

It is well that Mr. Witting has emphasized the appropriateness of using the net calorific values at 62 deg. F. when referring to combustion of gases containing hydrogen and hydrocarbons.

In gas producer practice an equally important detail is the sampling of gas. The superior reliability of continuous sampling extending over a period of several hours as compared with "snap" or instantaneous samples should be beyond discussion, yet some engineers prefer snap samples. This is especially important in connection with hand operated or partly mechanical producers in which "breaking down" of clinkers, and fires, and ash cleaning occur two or three times a day. The advent of the continuously operated completely mechanical producer minimizes the difference between continuous and "snap" gas samples. All discussions and calculations of the present speaker have and are based on continuous gas samples.

B. R. Shover: There was a point in regard to the use of "fines" in producers which is verified by an experience. A mechanically stroked producer house making gase for open hearth furnaces was operated on crushed coal which had passed over a screen, the fines going to the boilers, the arrangement resulting in a minimum of clinker. These producers were equipped with multi-jet steam blowers, but the quantity and quality of the gas was such that the open hearth furnaces would not produce to capacity. The multi-jets were replaced by turbo-blowers with a three-way valve in the exhaust for regulating the amount of steam added to the air, with most satisfactory results. The furnaces went up in output, coal consumption decreased, as did also roof and wall repairs, the better quality of the gas undoubtedly having as much to do with the improvement as did the larger quantity which the producers yielded. There was some trouble with the turbo-blowers, also higher cost of upkeep than for the multi-jets, but this increase in cost was more than compensated for by the larger ingot output, which, after all, is the governing factor.

I am also inclined to question the statement that men of higher intelligence are required to operate this type of blowing equipment than for steam-jet blowers. At the plant of the Tata Iron and Steel Company in India, the air for blowing the producers was furnished by a large fan and distributed by piping similarly to the way in which a bank of cupolas are blown, and live steam, controlled by a hand valve, admitted as required.

In 1914-15 and 16 the producer house was in charge of an Indian graduate from a law school, the crew being entirely Indian, not one of whom had ever seen a gas producer prior to his employment there. Labor was cheap, so one chemist was kept constantly taking gas samples, and I have never seen gas of equally even and good composition made anywhere else. I am sorry I do not have at hand the coal consumption per ton of ingots, but considering the extremely high ash content, it compared favorably with the best practice in this country.

A. Steed: There is one point I have not heard brought out. What is the value of the preheating the steam and what is the practical limit?

J. W. Spitzglass: I would like to ask Mr. Chandler and the others experienced in producer operation, what would happen to the efficiency, to the capacity rather of the producer, if the air blast was preheated, say, to 1,000 or 1,200 deg. F.? The reason I am asking that question is this: At a recent meeting of the Illinois Gas Association in Chicago, a paper was presented on experiments with preheated air for water gas generators. In those experiments the preheating of the air was done by the blast from the generator which is discharged to the atmosphere, but the question was mainly of capacity. It was stated that it actually required more pounds of coal, or coke, per thousand cubic feet of gas when the air blast was preheated, and even the capacity of the gas generator was reduced due to the preheating.

Yesterday we heard a paper on preheating air to boilers. I thought that was an entirely different op-

eration. The paper presented this morning came a little closer, because in that case the fuel bed was quite heavy. This present paper is still closer, because the producer and the water gas generator is continuous in the producer, while in the water gas generator it is intermittent. Taking this into consideration I am inclined to believe that some light might be thrown on the subject if we analyze what would happen to the producer when the air is preheated.

W. Dyrssen: I must say that I think that this is an extremely timely and valuable paper, and should be read and re-read and then read again by everyone who has a producer. This paper should be kept on the desk and referred to frequently and not laid aside. It points out the great improvements that can be accomplished in gas producers today.

There is only one point here in the tests that should have been taken care of, and that is the mositure in the gas. The moisture content is not given and I think this is extremely important. We talked about two or three per cent CO_2, but at the time there might be five or six per cent H_2O in that gas by weight and how that lowers the efficiency of the gas and the B.t.u. content on a dry basis is a question worth while considering. Unless the moisture content has been taken into consideration, the results do not indicate what they should.

The best way to do this is to get the blast temperature and figure the saturation point. As Mr. Chandler pointed out in his paper there must always be some moisture present in it in the form of fog or condensed moisture. That might vary the thing a great deal. The volume of the steam will have considerable bearing, especially if the steam is wet. In most cases I think that steam goes into the producer, if it isn't trapped out, and I do not think this is generally done.

It has been claimed that the moisture that is condensed in the blast is trapped in the ashes before it reaches the gasification zone. I do not think that is true in the majority of cases, since they are too hot at that point. In the majority of them, quite a lot of moisture in addition to that from the blast comes from the water seal.

In Mr. Chandler's balance, practically all of the moisture that is calculated in the blast is shown as decomposed. Of course, these figures are correct but I think that considerably more moisture actually enters, which passes through the producer and appears as moisture in the gas and for this reason the moisture in the gas should be also measured and I do not think this is a very difficult thing to do. It should be done.

A. G. Witting: I think you can calculate pretty closely the moisture that goes with the gas both from the coal and from the steam-air blast. You will find that even with the very best kind of gasification by means of steam jet blowers not more than 50 per cent of the steam is dissociated and converted into fixed gas, and that consequently more than 50 per cent of the steam follows with the gas.

W. Dyrssen: That is also my impression that 50 per cent of it is in that condition, and of these figures I think about 80 to 90 per cent was decomposed. I do not think that so much is decomposed but that other sources of moisture should be taken into account.

H. C. Siebert: Mr. Chairman, there are several points that I would like to mention in connection with Mr. Chandler's interesting paper—some questions that were asked by other speakers. I think it is very important to distinguish between different grades of coal.

In a given producer with a coal of a certain physical and chemical nature, particularly as regards ash, sulphur, iron in the ash, etc., we get a certain gasification, perhaps the favorable gasification, but when we change over to another coal and particularly if that coal contains a large amount of fines, that gasification rate will drop considerably and the gas quality will also be of a lower calorific value.

We have made in the past experiments on various producers, operated on different coals. In one case we used perfectly clean coal—the coal passes over an inch and a half screen and through a two and one-half (ideal), in spite of this, we cannot maintain an average monthly gasification rate of 25 pounds per square foot.

We also made some experiments on superheated steam. We have had as much as 300 deg. F. superheat at the nozzle, the nozzle pressure being perhaps 25 pounds, but we could not notice any advantageous effect upon gas quality or producer efficiency. Apparently the quantity of heat introduced into the superheated steam was so little that it didn't change the phase of the operation in the producer.

I also agree with Mr. Dyrssen that I believe a considerable amount of moisture in many cases comes from the water cooled ash pans of the producer, and I believe that it is just as important to make moisture determination in the gas as well as a determination for other constituents.

We are speaking of high gasification rates, 50 lbs. What I would like to see is a producer with a gasification rate of 250 pounds per square foot. And that leads me to a process of reasoning that is parallel to Mr. Wittings, but instead of manufacturing gas or converting bituminous coal in a nitrogen recovery by-product bituminous coal producer plant, I would say gasify all of the bituminous coal in a by-product coke plant and use the coke of certain sizes in the producer, generate steam by the sensible heat in the gas, thus cooling it down to perhaps 500 or 400 deg., if you please, then pass the gas through a scrubber, pump it into the same system that we have in the coke oven plants and transmit it under pressure to the plant as a whole. Considerable gain in the fuel economy of a steel plant could be made in this way.

Martin J. Conway: Inasmuch as the blast temperature indicates the weight of moisture per lb. of coal gasified, has Mr. Chandler had any experience in the use of atomized water in the blast? This of course would mean that an indicator showing pounds of water per minute or other unit of time would have to be used, instead of a thermometer to measure the blast saturation.

F. E. Leahy: One thing that was brought out very clearly in this paper, and I think did not receive the attention it deserved, was the limitations placed on the gas producer by the coal actually used. This paper brought out that it is important that the coal be properly prepared, to give the desired results.

In various sections of the country producers made by the same concern will run at a gasification rate varying from 25 to 50 lbs. of coal per square foot of fire area. The representatives of these manufacturers naturally call attention to the high rates of gasification obtained from their producers. They are also willing

to make guarantees to duplicate these results, but it is not always emphasized that the coal used is specifically limited to the characteristics of that used on the test. Then, when the producers are installed and an attempt is made to obtain the high rates of gasification, the users are disappointed to find they cannot secure as high rates as anticipated.

The manufacturer naturally stands back of his guarantee which covers the coal specifications, and if a high rate of gasification is desired it is necessary to change from the grade of coal used to a more satisfactory grade.

Many plants purchase coal for use in gas producers and boilers, and it is rare to find a plant so balanced that the slack from the coal can all be consumed in the boilers. If this is not the case, it then becomes necessary to use the balance of slack not required by the boiler house in the gas producers. This immediately imposes an extra duty on the producers, and as the percentage of slack to lump coal increases, there is a corresponding decrease in the maximum rate of gasification.

From this it would appear that more attention should be directed along the lines as indicated in the paper today. The conditioning of the coal should receive the proper consideration. The fuel available should be studied from the economic side to determine the number of producers required, the rate of gasification possible for the required amount of gas. This will also detremine such details as the desirability of using either a Steam Jet Blower or a Turbo Blower.

It has been brought out quite clearly in the discussion that, mechanically, it is now possible to obtain a satisfactory Turbo Blower for gas producer operation. The use of this apparatus offers exceptional possibilities in obtaining a high rate of gasification in a very efficient manner.

Another point to be considered is the method of feeding the coal to the producer. A great advance has been made in mechanical feeding, and it is now possible to obtain very satisfactory feeding of the fuel, especially when the coal has been properly conditioned.

In the paper today attention was called to the importance of knowing the fusing temperature of the ash in the coal. This has long been realized by the central station power plant operators. It is quite customary in many of these plants, which use underfed stokers, operating at a high rate of fuel consumption to determine the ash-fusing temperature for all lots of coal used. It was discovered that the capacity of the stokers could be materially reduced if coal contained an ash of a low fusing temperature.

The same idea applies to the use of coal in a gas producer and a knowledge of this is just as important as anything previously mentioned to obtain a high rate of gasification.

In discussing the use of the proper coal with the author of the paper, it was brought out that at the plant in which he is located changed from the mine they had been previously obtaining their coal to another mine; the coal from which was so much better that they now obtain all their coal from this mine for their gas producer operation.

W. Chandler: Most of the discussion has brought out the point that while producers are one of the older pieces of apparatus which we have, they have never received close attention in steel works. When you get down and really try to improve practice that has been going on for a number of years you find that something you have taken for granted for a long while can be changed considerably, and that is really the condition the producers have gone through in the last few years.

One point Mr. Culbertson brought out, and which Mr. Shover answered, I think, was in connection with the intelligence of the operator that is required for the turbo-blowers as against the steam jet blower. We were very careful that the operator who was going to make gas would know that he had one valve to turn on, just the same as he did when he had the steam jet blower, and there is absolutely no difference in what he has to control. If the amount of steam per pound of air being introduced has to be changed, it is caused by a change in the character of the control that is being fed to the producer. The required moisture is practically a fixed amount for a given quality of coal, and when you know ahead of time that you are going to change the character of the coal the moisture can be changed accordingly, and will remain at the new point until you get back again on the other grade of coal that you were using.

I want to bring out at this point what Mr. Leahy spoke about, the condition of the coal. There are a great many cases where you are forced to use very poor grades of coal. If poor coal is at hand, there is no sense in throwing it away, it can be used in the producer, and the thing to do is to make gas with it and get rid of it, but if you are using the producer gas to make a certain quality of steel and a certain tonnage of steel from the furnace, you practically are forced to condition your coal before it enters the producer. It is not a case of will the producer handle it or not, it is really a case of what kind of steel you are going to make with the gas you are producing. For that reason we have found a regular conditioning of the coal going through the producers which furnish our open hearth furnaces is really a great requisite.

Another point that Mr. Culbertson raised was in connection with the efficiency of the steam jet blower. The efficiency of the steam jet blower shown in the paper was obatined on a blower of the type usually installed with producers. If the Chapman Company has been able to reduce the consumption of the blower installed with their producers to the figures quoted the performance is very creditable.

The main point for comparison of the steam jet and the turbo-blower is not so much in the efficiency that you obtain, it is the ability to control the amount of steam going into the blast which cannot be done with the steam jet blower.

Mr. Steed asked about the value of superheating steam, and I think Mr. Seibert has already answered that question as far as a great deal of superheat is concerned, but all of us, I believe, realize that a certain amount of superheat, that is, at least of dry steam, is a very fine thing for the producer and is what we should have.

Preheating the air blast going into the producer would not be an advantage unless it was desired to introduce a large amount of moisture with the blast. It is imperative that too high a temperature is not maintained in the producer. If you preheat your blast it is going to raise the temperature of your combustion zone immediately and more moisture must be

introduced to keep the temperature down, so I would hardly think that preheated air would give many advantages.

However, Mr. Dryssen in a paper on producers which he gave last spring before the American Iron & Steel Institute, has made some calculations which are most interesting because they show the benefits thermally that can be derived from preheated air blast before the producers.

I believe that covers most of the points, except Mr. Dryssen's remark about the moisture in the gas. I readily appreciate that the moisture is a very important thing, but the fact remains that as your temperature of combustion zone goes up, the amount of water vapor dissociated goes up, and the smaller amount of moisture appears as moisture in your gas, so that where you work at the most economical point in your producer you will have a considerable reduction in the amount of moisture as such in the gas going out from the producer outlet.

Measurement of Input and Output in Boiler Rooms

By J. M. SPITZGLASS*

ONCE upon a time, in a fairy tale by a famous poet, there was a magic pine tree in the midst of a forest. A squirrel playing on top of the tree amused itself by cracking golden shells off the emerald kernels of the nuts growing on the magic tree. The story has it that a faithful monk was appointed to keep a record in the treasury of both the golden shells and the emerald kernels.

If the iron and steel industry may be compared to the magic tree of the fairy tale, you, the engineers of that industry, are the ones to crack the nuts with a song. I will, temporarily, take the position of the faithful monk, and give you a few examples of the counting and the measuring, limiting myself to the material quantities involved in the operation of the steel plant boiler room.

When I was called upon to prepare this paper for your convention, I felt very timid and decided to go to the iron and steel metropolis and get acquainted with the actual conditions. Our friend, Mr. Chandler, who is mainly to blame for my predicament, gave me a good deal of encouragement. I asked him how far I could go into the details of the subject about the boiler room.

"Well," he said, "you know you are going to talk to engineers who are quite familiar with boiler room operation."

That was just what I was afraid of. If they were not so familiar with boiler room operation I would have felt much more comfortable. Still, I knew that I would have that much less to talk about. Then, following the process of elimination, I asked Mr. Chandler: "Why do you want to measure the input and output of boiler rooms? What good will it do you?" My idea was, inasmuch as you are all familiar with operation of boiler rooms, I need not worry about it, and if you really have no reasons for measuring the quantities, the paper could have been submitted by title only. Mr. Chandler stopped me short on that. He gave me to understand that the engineers of the iron and steel industry have good reasons for measuring quantities in the boiler room, if they wish to obtain the highest efficiency in their operation.

It was not so long ago that the task of the faithful monk was a very hard one. He first had to prove to the operator the need for measuring the materials before he was allowed to show how they could be measured. I am gratified to realize that we now have passed from the stage of "why" to the stage of "how." Consequently, the object of this paper should be to show how the material quantities can be measured accurately and conveniently in and around the boiler room.

*Republic Flow Meter Company, Chicago, Ill.

Flow Versus Quantity Measurement.

Measuring the input and output of a boiler room, or at any other point of the power plant, is relatively an easy task. In my early experience with the Peoples Gas Light & Coke Company of Chicago, I was often engaged in running a check on the large quantities of coal and coke stored in the gas works. That was a difficult problem. The substance to be measured lay solid on the ground, most irregular in shape and form. I had the alternative, either to move the whole bulk through containers, filling and emptying each container and registering the amount, or to move around the coal pile myself and make a survey of the contents. The former method was out of the question as being too expensive and too troublesome. We usually chose the second one, and after surveying the pile many times in every direction, I made a rough estimate of the cubical contents, guided by the conviction that a shortage in the future would not necessarily hurt in the present.

Compare with this the ease and convenience in measuring the input and output of the boiler room. The solid fuel is conveyed to the furnaces in a regular stream. The fluid material passes through carefully gaged pipes. It is moving through the pipe by its own momentum; the nature and substance of the fluid is well known, or can be easily obtained by proper instruments. All that is necessary is to obtain the speed or the motion of the fluid as it is conveyed through the pipe.

The measurement of fluids is the predominant factor in the boiler room of the steel plant. While the output of the boiler room—steam—is the same as in other industries, the input includes more than 50 per cent of blast furnace and by-product gas. Besides, the measurement of the solid fuel is always done in one way or another when it is delivered from the mine.

We shall consider this measurement after we discuss the main subject, the measurement of the fluids, the gas, the water, the steam, and, incidentally, the air draft in the boiler room.

Measuring Flow of Fluids.

All fluid measuring devices consist of two major parts; one is the primary element which comes in contact with the fluid and is acted upon by its motion; the other is the secondary element which translates the action of the fluid upon the primary device into rates of flow, weights and volumes respectively.

The primary device may consist of a pitot tube or an orifice plate, inserted into the pipe for the purpose of obtaining a differential pressure, which is used as a criterion of the rate of flow through the pipe.

The secondary device may be a simple U-tube gage, or Manometer, which balances and indicates the differential pressure produced by the primary device, or differential medium. In the commercial meter the secondary device translates the differential pressure into arbitrary units of flow.

The principle of measuring fluids by means of a differential medium was well known to students of hydraulic engineering long before the advent of the flow meter as a commercial article. The principle has been applied in colleges and laboratories in tests with weirs, venturi tubes, pitot tubes, nozzles and orifices.

Naturally, in the case of a laboratory or college test, there was little trouble experienced in obtaining the true pressure difference corresponding to a given flow. In each case the piping was properly designed to fit the particular conditions. Leaks in the piping, air or water bound extensions were carefully eliminated from the connections. Gages were read with laboratory precision so that there could be no doubt in the results.

The application of similar devices for practical purposes is a comparatively recent but very comprehensive development. The present state of the art is such that an orifice can be designed to give a definite pressure difference for a very wide range of flow under any condition of pressure or temperature. The experimental work has been carried to a point where the orifice can be depended upon to give results accurate within a fraction of a per cent. In fact, the experimental work has been so carefully performed that, in every day practice, inaccuracies caused by errors of observation are greater than those due to errors in orifice calculations. The secondary element, that is the indicating or recording portion of the meter, will record a rate of flow, or total flow, corresponding to a definite differential pressure with very great accuracy. Both the orifice calculations, or rather orifice data, and the recorder construction, are dependent upon the meter manufacturer. Fortunately, these two things have been developed to a very high stage.

The connecting link between these two parts is the connecting piping from the high and low pressure sides of the differential medium to the two connections of the secondary element. This element, whether a Manometer or Meter Body, will be actuated by the pressure difference delivered, whether this is the actual pressure produced by the differential medium, or a pressure modified by faults in the piping. This is one matter that is dependent to a large extent upon the meter user and is the cause of the majority of meter troubles.

Practical Application of Measuring Devices.

Fig. 1 illustrates the simplest form of primary and secondary device as applied to the measurement of fluid through a given pipe. For the purpose of fluid measurement in the boiler room, the thin plate orifice is much preferred to the pitot tube, because of its higher accuracy and its adaptability to various quantities of flow. New installations should be designed to allow sufficient length of straight pipe and provide proper flanges for insertion of orifice plates in every pipe line to and from the boiler room. It should be borne in mind that a pipe line without a provision for

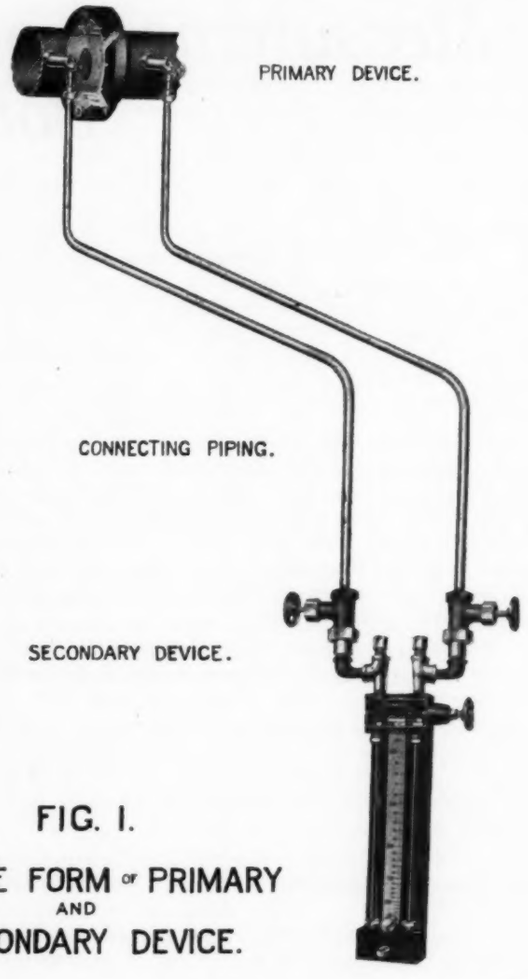


FIG. 1.

SIMPLE FORM OF PRIMARY AND SECONDARY DEVICE.

A.I.S.E.E. APRIL, 1924.

a differential medium is one of the greatest obstacles in the path of efficient operation in the boiler room.

In old installations, where the piping conditions are not suitable for the insertion of an orifice plate, a pitot tube may serve the purpose, provided there is sufficient straight pipe in front of it (6 to 10 pipe diameters). In cases where the maximum flow cannot be estimated, it is well to insert the pitot tube to obtain the data for determining the size of the orifice.

Installation of Differential Medium.

The proper installation of an orifice plate in a given pipe requires the consideration of the following items:

1—Size of orifice. (Orifice ratio.)
2—Location of orifice plate.
3—Proper spacing of pressure taps.
4—Pressure connections to gage. (Or commercial meter.)

These will be discussed in the order in which they are taken up in proceeding with an orifice installation.

1. Size of orifice. (Orifice ratio.) The size of the orifice and the corresponding orifice ratio is to be gaged accurately for determining the so-called coefficient of discharge and the amount of flow corresponding to a given unit on the Manometer (or commercial meter).

The orifice ratio, as referred to in this paper, is obtained when the orifice diameter squared is divided by the pipe diameter squared. This is the ratio between the circular inches of the stream through the orifice to the stream through the pipe.

For any given installation, the orifice ratio should receive the first consideration. If the orifice ratio, as determined from the given conditions, is 20 per cent or less, the consideration of proper location and spacing is practically eliminated. Such an orifice may be installed in front of any fitting, with the exception of a globe valve. An orifice ratio as high as 70 per cent will give accurate results if there is sufficient length of pipe on both sides of the orifice plate. A convenient method of arriving at the proper size and ratio of the orifice is given in the second part of this paper under "Determination of Constants."

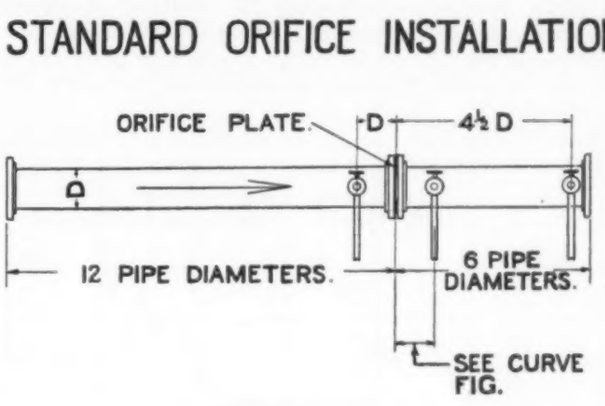
2. Location of orifice plate. The most careful consideration should be given to the proper location of the orifice plate. By proper location is meant the placing of the orifice in the pipe so that the flow will approach the opening in straight and parallel lines.

The condition of the piping, before and after the orifice, has a very marked effect on the accuracy of measurement. Bends in the pipe, tees, obstructions, in fact, anything that will produce an uneven or a swirling motion changes the coefficient or discharge considerably, necessitating a separate calibration in each case.

(a) Standard installation. Fig. 2 shows the conditions necessary for a standard installation of an orifice plate. Twelve diameters of straight pipe in front of the orifice plate are allowed to straighten out any irregularities in the flow. Six diameters of straight pipe are shown beyond the orifice plate, so that there may be a complete restoration of pressure before the stream is diverted from its path. If the pipe follows a right angle bend in the line, it is well to partition the inlet by vanes to insure the even distribution of the flow through the whole section of the pipe. These are the conditions under which the orifice coefficients were determined in the research laboratory of the Republic Flow Meters Company, as reported in the paper, "Orifice Coefficients," by the writer, submitted to the American Society of Mechanical Engineers in December, 1922. A reproduction of the outline of the piping used in the original tests is shown in Fig. 3.

It is not always possible to obtain such ideal conditions for the location of an orifice plate. It must be clearly understood, however, just what deviation from the standard may be allowed and what the effect will be on the accuracy of the measurement. In general it may be said that the necessity of adhering to standard conditions depends upon the ratio of the orifice to the pipe area. When this ratio is very small, a slight disturbance in the pipe seems to have a relatively small effect on the accuracy of the measurement. On this account it is very often possible to place a small ratio orifice under most unsatisfactory conditions of piping, where the medium or large ratio orifice would not operate satisfactorily.

The condition of piping immediately beyond the orifice is not as important unless far connections are used, as will be explained later, in which case five



diameters or more are absolutely necessary. For close connections of the pressure taps, shorter distances may give sufficient accuracy in measurement.

(b) Effect of irregular piping. Fig. 4 shows an installation of an orifice plate at the end of an expansion loop on the top of the boiler. The orifice is located in the vertical extension in front of the gate valve. It is recommended that in similar cases the orifice ratio should be limited to 50 per cent.

Long radius bends and expansion loops may be considered the nearest approach to a straight length of pipe. The effect of the centrifugal force is minimized by placing the pressure taps at right angles to

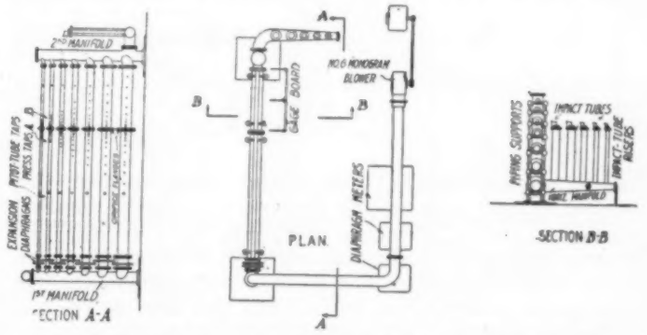


FIG. 3 GENERAL LAYOUT OF RESEARCH LABORATORY EQUIPMENT

the plane of the bend. In general, wherever the orifice is close to a given fitting the pressure taps should be made as close to the flange as possible.

Fig. 5 is intended to demonstrate the limitations set by elbows or bends in a given line. tI is always unsatisfactory to place an orifice after an elbow while in front of the elbow low ratio orifices may be used with satisfactory results. In all such cases the piping connections should be made as close to the flanges as

possible. The suggested limits of the orifice ratio are shown on the figure.

3. Proper spacing of pressure taps. Fig. 6 shows diagrammatically what happens when an orifice plate is inserted in the path of the moving fluid. As the particles of the stream approach the opening of the orifice, they begin to converge toward the center of the pipe. The particles in the center of the pipe, which are moving the fastest, do not change their direction, while the particles in the outer section of the stream have to move toward the center of the pipe in order to get through the opening. The change in direction of the stream as it hits the orifice plate creates an increased pressure immediately in front of the orifice.

After the stream has passed through the orifice, it continues to contract for a short distance. Thus, we

BOILER OUTLET.

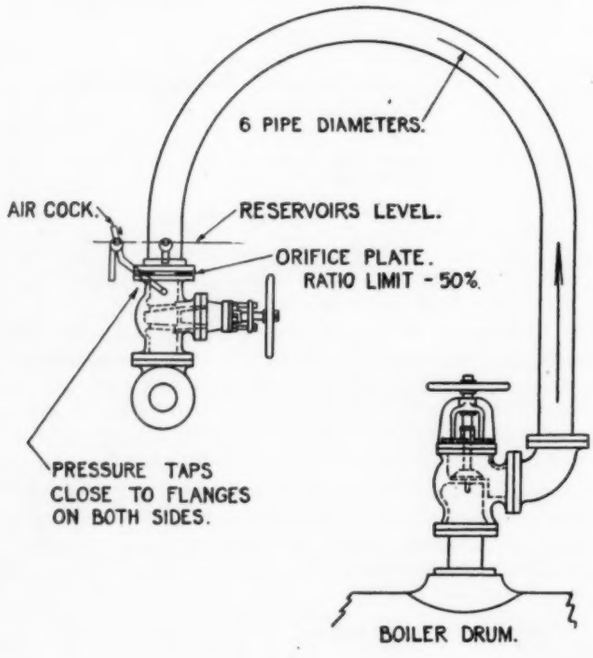


FIG. IV.

A.I.S.E.E. APRIL 1924.

have a section beyond the orifice plate where the cross-sectional area of the stream is actually smaller than the orifice opening. Beyond this point, the stream begins to widen again and at a distance of about 4 to 5 diameters the stream completely fills the pipe as it was before it entered the region of the orifice.

You will note that Fig. 6 shows three sections as the best locations of pressure taps, because at these sections the flow is more or less parallel to the walls of the pipe. The pressure difference between the first and the second section is the maximum drop across the orifice. The difference between the first and third gives the loss of pressure through the region of the orifice. The difference between the second and the third is the pressure regained between the section of greatest contraction and the section of normal uniform flow.

In the practical application of the orifice plate, we designate the use of the first and second sections as the Vena Contracta (C_v) connections. The use of the first and third sections, as the restoration point (C_p) connections. It is recommended that the C_v connections should be used in all cases where the differential pressure does not exceed the capacity of the Manometer or commercial meter. With these connections, the

ORIFICES NEAR ELBOWS.

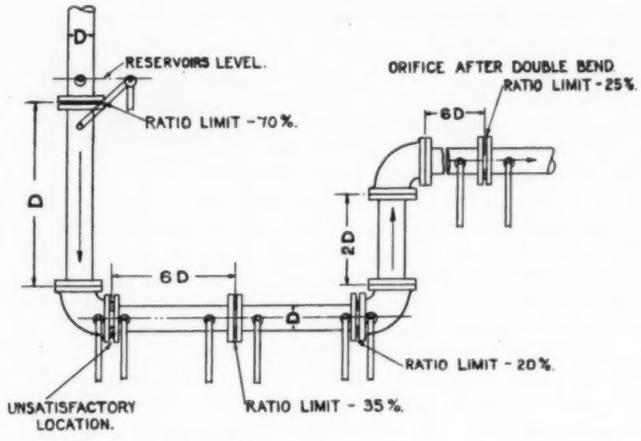


FIG. V.

A.I.S.E.E. APRIL 1924.

maximum drop of pressure is utilized as a motive power for the meter, or as an indication on the Manometer. There are cases, however, where the C_p connections are used to great advantage. If the flow has an original high velocity through the pipe any restriction will bring about an excessive drop through the orifice. In such cases, the restoration of pressure is quite significant and the use of the C_p connections will bring the differential within the range of the secondary device.

In all cases of straight pipe, the high pressure connection could be made between ¾ to 2 diameters in front of the orifice. (One pipe diameter is used in general practice.) On the low pressure side, the C_p connections are placed at 4½ diameters from the

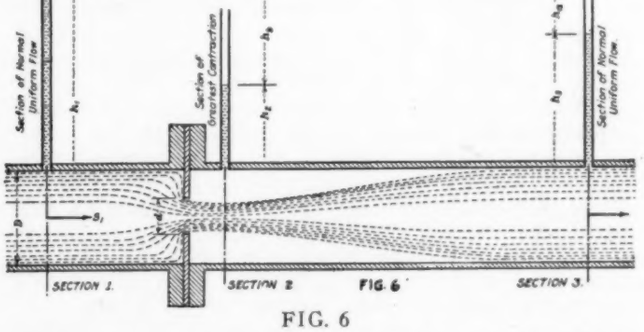


FIG. 6

orifice. The C_v connections are aimed to be placed at the section of greatest contraction or vena contracta.

Fig. 7 shows the spacing of the taps at the vena contracta in percentage of diameter length corresponding to the given orifice ratio. The center line indicates the exact location of the contracted section. The two outside curves marked "minimum" and "maximum" show the limits to which the taps may

be shifted without varying the accuracy more than one-half of 1 per cent. The actual spacing should be made as nearly as possible to that given by the center line on all straight pipe installations. In cases where the orifice must be placed in close proximity to a fitting in the line, both connections should be made invariably as close to the flange as possible. In such cases the small error resulted from the deviation of the spacing is insignificant in proportion to the effect of the fitting in the line.

4. Pressure connections. As previously stated, the pressure connections are the connecting link between the primary and the secondary elements of the measuring device. The successful operation of the meter depends entirely upon the attention given to them. The neglect of the operator in taking care of the connections cannot be overcome by any refinement on either the primary or the secondary device.

Great care should be exercised from the very start in drilling and tapping the pipe on both sides of the orifice plate. It is imperative that the connecting nipples do not project inside the pipe because if they do eddies will be set up which will produce an aspirating effect that will in turn result in a fictitious pressure delivered to the secondary device.

In measuring steam the connecting piping is filled with water of condensation. It is necessary that the level of the water in the two pipes be maintained equal at all times. Should there be a variation in this water level, the pressure difference will be effected to the extent of this variation and, consequently, results will not be correct.

It is necessary that the connecting piping be graded so that any air that may be liberated by the water will work back and escape into the pipe as, should there be a collection of air on one side, it is obvious that the pressure will be affected. In the measurement of air or gas, the piping must be similarly graded so that all entrained moisture will come down towards the secondary device, as it is very hard to affect the draining back into the pipe. In most of the secondary devices provisions are made for the accumulations of ordinary amounts of moisture. Where the accumulation is out of the ordinary, proper provisions should be made to collect the moisture before it enters the chambers of the secondary device and to dispose of it at regular intervals.

Above all, it is necessary to make certain that there is absolutely no leak between the primary and secondary devices. There are cases where the static pressure in the line is measured in hundreds of pounds per square inch, while the differential is measured only in fractions of an inch of water. Any leak that will occur on either side of the instrument, while having very little effect on the total pressure, may have a tremendous effect on the differential pressure and, consequently, on the accuracy of the measuring device.

The Secondary Element of the Measuring Device.

The scope of this paper does not permit us to go into the details of the commercial devices of fluid meters. There are various appliances on the market that have been demonstrated to register accurately the differential pressure obtained by the primary device. The best method of determining this accuracy is to compare the registration of the instrument with a standard column of mercury or water. Such a test can easily be duplicated in the plant by the operator.

There are cases in practice where one kind of instrument will suit the conditions better than another. In the steel industry you are confronted with the problem of measuring fluctuating flows, as for instance, the supply of steam to a blooming mill engine. For such conditions a mechanically operated instrument would render the readings inaccurate on account of the inertia of the moving parts. When the instruments are operated electrically, the varying flow is integrated directly from the instantaneous heights of the differential column.

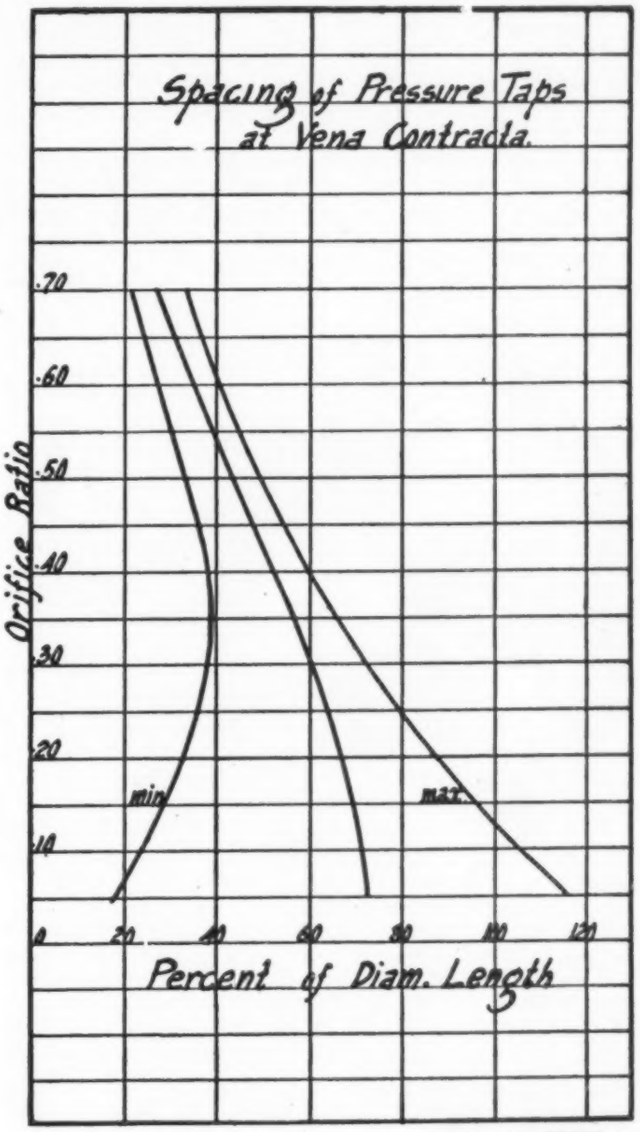


Fig. VII

We have several installations where we are measuring the steam generated by waste-heat boilers on water-gas machines where the generation of the steam is following the blasting period of the water-gas generator. The operation of the machine is such that the boiler changes from zero to full load every three or four minutes. Several tests were made by the operating engineers with the following results:

TEST OF STEAM FLOW METERS

North Station—Peoples Gas Light & Coke Company

Date	Duration Hours	Boiler	Water Weighed lbs.	Water by Meter lbs.	Percent Error
11/26	11¾ hrs.	No. 13	40,095	39,964	— .3%
11/28	15 hrs.	No. 11	57,518	57,211	— .5%
11/30	12 hrs.	No. 12	51,640	52,278	+1.2%

A record chart of the second test is given on Fig. 8. The details of the tests are available for your information. I will merely state that the tests were made under ordinary working conditions and they were checked over carefully so that there could be no doubt of the results.

In general, however, an overall test of the meter is neither necessary nor conclusive proof of the accuracy of the secondary device as such. As I demonstrated before, the accuracy of a flow meter depends first of all on whether the pressure difference transmitted to the secondary device is the true equivalent

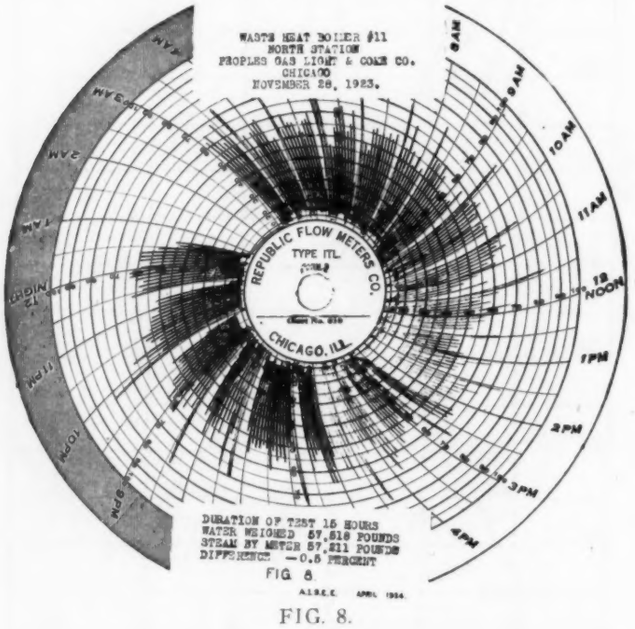


FIG. 8.

of the flow of the fluid through the pipe. When that part is made certain by the proper installation of the primary device, it is very easy to run a water column test to establish the accuracy of the secondary device.

Measuring the Air Input to the Boilers.

Of the fluids handled in the boiler room, the steam, the water, and the gas fuel are conveniently measured by the flow meter.

The supply of air to the furnace presents a problem which does not lend itself to a direct solution. It differs greatly from the measurement of the other fluids because the air seldom passes through definite channels on its way to the combustion chamber.

It has been stated repeatedly by authoritative persons that the air supply may be determined by measuring the differential pressure between two given sections of the boiler along the path of the products of combustion. The theory is that the resistance to flow is a criterion of rate of flow in the same manner as the pressure difference produced by an orifice or other differential medium in a pipe.

It is rather difficult to accept such theories when we consider all of the precautions previously recommended for other measurements. The law of physics holds true that the inertia of the fluid is proportional to the velocity squared times the density. The density is a function of the temperature and composition of the gases. It varies to a large extent as the products of combustion pass from one section of the boiler to the other. That is, the density varies considerably between the two points at which the two pressures are obtained. The velocity is a function of the same varying density and also of the areas of the passages, which may vary from the continuous accumulation of soot and dirt on the tubes. The impact, as I stated, represents this velocity squared times the density, and it is very doubtful to my mind whether we can base operation on an index that is affected by such indeterminate quantities. If we add to this the possibilities of leakage in the setting, the possible infiltration of air over the fire, which may also be a variable quantity, the possible changes in the fuel and in the condition of the fuel bed, we must come to the conclusion that if we desire to measure the air consumed in the combustion of the fuel we must provide proper channels for the supply of the air to the combustion chamber. If this is impractical, it is best, in my opinion, to use a direct method of determining the quality rather than the quantity of the gases leaving the boiler. A continuous record of the temperature and the CO_2 contents of the flue gases, and the rate of flow of steam generation, will give the information necessary for intelligent boiler operation.

Draft gages are being used extensively to indicate the varying conditions inside of the boiler setting. Skeptics say that draft gages will indicate air conditions only slightly better than anyone can guess at them. This is probably due to the limitations of the glass tube indicating gages. Those gages as a rule require entirely too much attention and care to keep them in good trim around the boiler. The indications are always uncertain on account of the zero level, and besides, it is very hard to read them at a distance, and no operator has the time to strain his vision for an exact reading of an instrument. The Republic Flow Meters Company has now developed a line of gages in principle and appearance similar to the dial of the commercial flow meter, both indicating and recording. Such instruments can be seen at a distance, and the hand on the wall is the best indication that will appeal to the operator.

Under forced draft, it is very necessary to know the conditions in the various compartments of the boiler and the furnace. There are many uses for a good draft indicator, with which you are all familiar, but as I stated before, I am not at all convinced that the draft instrument, or any similar indication of differential pressure through a given part of the boiler, is a criterion of the amount of air supplied to the boiler. The fireman will find good use for a draft gage when he changes the damper, because it will always indicate the effect and the extent of that change. It will only show the relative change that is taking place in the condition of the boiler at the moment under observation.

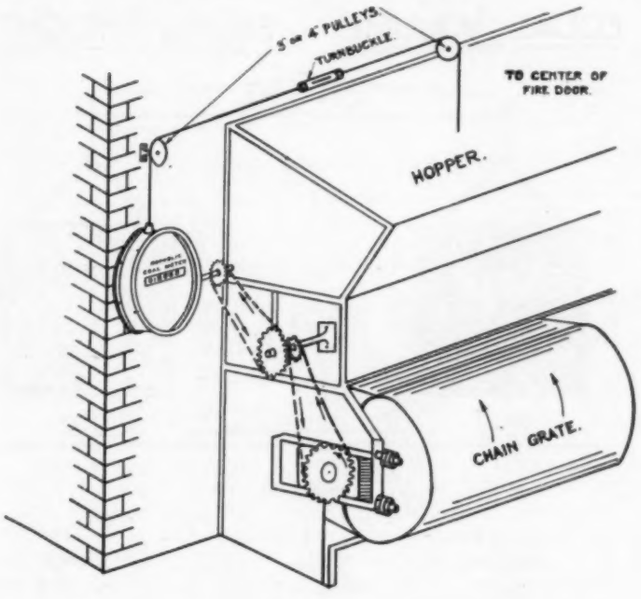
Measuring Flow of Coal into a Boiler Furnace.

Fig. 10 shows the installation of a coal flow meter as applied to a chain grate stoker. The meter records the product of the chain speed and gate open-

ing. Since the width of the gate is constant, this product represents the volume of coal passed in unit time.

The movement of the grate is transmitted through a revolving spiral cam to a revolution counter. A disengaging roller is placed parallel to the axis of the spiral cam and is connected to the gate by a cable. As the opening of the gate changes, the roller is moved back and forth parallel to the gears, the counter disengaging more or less, according to the position of the gate. Thus, the reading of the revolution counter is directly proportional to the volume of coal in cubic feet passed through the gate.

The measurement of coal by volume instead of by weight, eliminates the factor of moisture or wetness in determining the actual quantity of coal purchased at the mine, supplied to the plant and consumed in the furnace. This factor has always been neglected for obvious reasons. People simply did not know how to take care of it. A car load of coal, as weighed at the mine, contained a certain amount of moisture. The coal analysis, if any was made, gave the B.t.u. per pound of dry coal, but the price paid was based upon the weight of coal as



SUGGESTED METHOD OF APPLYING REPUBLIC COAL METER TO COXE STOKERS.

FIG. 10

mined and included the moisture content. If the moisture content was 10 per cent we would expect at least the same B.t.u. in the 90 per cent of the dry coal, or we would expect a corresponding increase in the B.t.u. of a pound of dry coal.

After going through various preparations, and the delivery of the coal from the mine to the boiler room, the moisture content of the coal, especially the wetness, varies considerably. The variations are such that in every day conversation, when speaking of the weight of coal, it is never certain at what stage of the process that weight was obtained. Was it at the mine at the time of loading, was it at the power plant at the time of unloading, or was it at the time the bunkers were filled, or as fired into the furnace? From the time the coal leaves the mine until it enters the furnace, it is being wetted intentionally and unintentionally, so that even neglecting the variation of the moisture in the coal as mined, the indefinite amount of water added to the coal makes its true weight an uncertain quantity, both with relation to checking the amount purchased and with relation to establishing the efficiency of a given boiler.

There is, of course, one alternative in the form of sampling the coal and running continuous analyses on the samples, comparing the quality of the given weight of the coal as it enters the furnace, with the quality of the same weight of coal as it leaves the mine. I do not know of any place where this is being fully attended to for each individual boiler; it is well nigh impossible to do it with any degree of accuracy.

All this work becomes unnecessary when the quantities are determined by the volumetric method of the coal meter. Consider a car load of coal as it is transported from the mine to the power plant and into the boiler furnace. Assume a quantity of, say, 50 pounds of coal at the mine isolated from the rest of the load by an imaginary box so that it is not separated from the rest of the coal. If the volume of the box was one cubic foot at the mine, it will remain one cubic foot during the process of transportation and it will still be one cubic foot when fed into the furnace, while the weight may change considerably, depending upon the amount of water that has been added to it intentionally and unintentionally from the time it leaves the mine to the time it enters the boiler furnace. It follows that the volume of the coal is the only quantity that remains constant during transportation. Furthermore, the volume of the coal is the only gage that indicates directly the weight of dry coal. If the imaginary cubic foot of coal, weighing 50 pounds at the mine, possessed 10 per cent of moisture, that cubic foot would represent 45 pounds of dry coal. It would still have been a cubic foot if the moisture were removed from it at the mine.

To sum up the situation, there is a definite quantity of one cubic foot. It would have weighed 45 pounds if it were dry. It weighed 50 pounds at the mine, because it had 10 per cent moisture. It may be 55 pounds when it reaches the boiler if there was enough water added to it. Isn't it logical to measure the coal by its volume, and from that measurement to transfer to the weight at the desired percentage of moisture, if the weight is required for checking or other purposes?

The moisture content is significant when considering the purchase price of the coal, because it has a bearing on the number of Btu. obtained per dollar. The generation of heat, however, is dependent upon the dry coal only, and the volumetric measurement is the one that represents the dry coal.

The meter under discussion is really a coal flow meter. It is interesting to note that in testing the meter, the flow of coal in cubic feet per unit of time is represented by an equation similar to the one representing the flow of fluids. The equation is:

$$F = C\,B\,H\,S$$ where,

F = Volume of coal in cubic feet corresponding to one unit on the meter.

C = Coefficient of discharge, similar to the coefficient used for fluid measurement.

B = Width of the grate.

H = Height of the opening.

S = Speed of the grate.

all measured in feet.

In conclusion, I wish to thank the Association of Iron and Steel Electrical Engineers for inviting me to read this paper, and I wish to express my sincere appreciation to my associates of the Republic Flow Meters Company, and especially Mr. George D. Conlee and A. F. Spitzglass for their assistance, which made it possible for me to present this paper in the form submitted.

PART II

DETERMINATION OF CONSTANTS

General Outline.

All scales of flow meters are subdivided to read in units of flow which are proportional to the square root of the equivalent differential pressure. The constant of the meter is a simple multiplier representing the value of one unit in pounds, cubic feet, or gallons, per unit of time, as the case may be. The divisions of the Manometer scale, shown in Fig. 1, are arbitrarily marked so that 100 divisions coincide with one-inch on the scale. Following the law of squares, a maximum height of 9 inches represents 300 units of flow. A general form has been adopted for determining the amount of fluid corresponding to a given unit on the flow meter scale. The formula is:

$$F = CD^2K_1K_2MS$$

Each letter in the formula represents a definite term as given in the following outline. The terms of the outline are explained in detail, as to their origin and use, on the following pages:

F = the constant for the given instrument. That is, the amount of fluid corresponding to one unit on the scale.

C = Coefficient of discharge. (See Fig. 9.)

D^2 = Pipe size factor. This term represents the number of circular inches in the cross section of the pipe where the fluid is being measured. See Table I for values of standard and extra heavy sizes.

K_1 = Scale factor.

K_2 = Density factor. (Tables II, III and IV.)

M = Correction factor for superheat, or quality of steam, or for temperature of gas. (Tables V and VI.)

S = Correction factor for specific gravity. (Table VII.)

It is obvious that for any conditions all terms in the second part of the formula are known quantities, so that the value of the constant "F" is obtained by simple multiplication of the given terms.

It may seem peculiar at the first glance that a very important item—the diameter, or rather the diameter square of the orifice—is eliminated from the formula. The reason is that practically in every case the formula has to be applied, primarily, for the purpose of determining the size of the orifice. That is, the formula has to be used before the size of the orifice is known. To say it in other words, the coefficient of discharge, whether calculated with relation to orifice area, or to pipe area, is a function of the ratio between those two areas. Consequently, if the coefficient were given on a set of curves with relation to the area of the orifice we would have two unknown quantities in the equation, the coefficient of discharge and the orifice area. For that reason, values of the coefficient were plotted such as would apply to the area of the pipe, and not to the area of the orifice. From the curve we obtain the corresponding orifice ratio which gives us directly the area of the orifice in terms of the known area of the pipe.

The first use of the formula is, therefore, in solving for the value of the coefficient of discharge for the desired maximum capacity of the meter. For this purpose the formulae will read:

$$C = F/D^2K_1K_2MS$$

For this formula the value of "F" is obtained by dividing the given maximum capacity into the maximum reading of the scale of the given meter. The other quantities are obtained from the following tables.

(C) Coefficient of Discharge.

Fig. 9 shows two sets of values for the coefficient of discharge for various pipe sizes. The first set is designated as C''_p, which refers to an installation

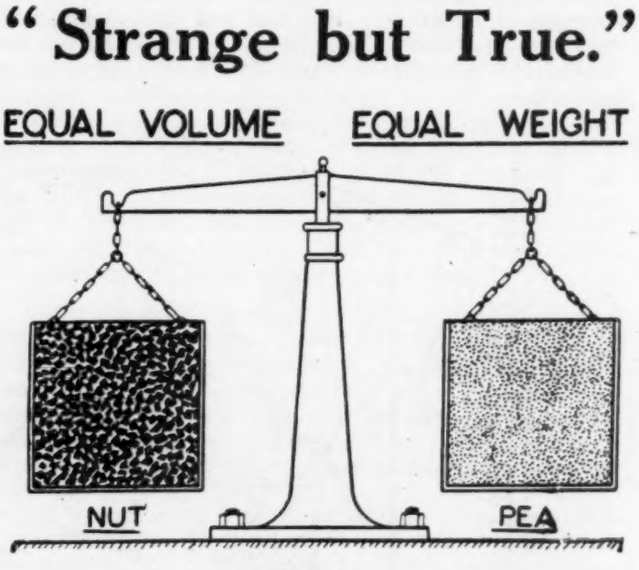


FIG. 9

where far connections are used; that is, where the low pressure tap is made 4½ diameters from the orifice plate. The other set, C''_v, refers to the ordinary connections where the low pressure tap is made at, or near, one-half diameter of the pipe according to the location of the vena contracta, as shown on Fig. 7. The curve may be used for two purposes:

1—When determining the orifice ratio (and the size of the orifice) for any given value of "C."

2—For determining the value of "C" for any given orifice ratio.

The value of the coefficient varies somewhat with the size of the pipe up to 12 inches, after which size the variation is not pronounced so that 12-inch coefficient may be applied to higher sizes of pipes.

The values for C_p'' are given for all ratios, mainly for the sake of comparison. For practical purposes the C_p connections are not to be used until the ratio passes 60 per cent on the C_v curve. That is, the only part of the curve used for practical purposes would be the last column to the right of the plate. The values of the coefficient were computed from Tables VIII, IX, X, XI, XII and XIII, given in the paper, "Orifice Coefficients," previously cited in the paper.

TABLE I—(D^2) PIPE SIZE FACTOR

The following table gives the internal diameter of various sizes and weights of pipe with the corresponding value of the internal diameter squared (D^2), designated as Pipe Size Factor.

I. D. WROUGHT IRON PIPE

Nom. Size	—Standard— Int. Dia. D	Factor D^2	—Extra Strong— Int. Dia. D	Factor D^2	Double —Extra Strong— Int. Dia. D	Factor D^2
1	1.049	1.100	0.957	0.916	0.599	0.359
1¼	1.380	1.904	1.278	1.633	0.896	0.803
1½	1.610	2.592	1.500	2.250	1.100	1.210
2	2.067	4.272	1.939	3.760	1.503	2.259
2½	2.469	6.096	2.323	5.396	1.771	3.136
3	3.068	9.413	2.900	8.410	2.300	5.290
3½	3.548	12.588	3.364	11.316	2.728	7.442
4	4.026	16.209	3.826	14.638	3.152	9.935
4½	4.506	20.304	4.290	18.404	3.580	12.816
5	5.047	25.472	4.813	23.165	4.063	16.508
6	6.065	36.784	5.761	33.189	4.897	23.981
7	7.023	49.322	6.625	43.891	5.875	34.516
8	7.981	63.696	7.626	58.141	6.875	47.266
9	8.941	79.941	8.625	74.391		
10	10.020	100.400	9.750	95.062		
11	11.000	121.000	10.750	115.562		
12	12.000	144.000	11.750	138.062		

LARGE O. D. PIPE

Outside Dia.	Int. Dia. D	Factor D^2	Int. Dia. D	Factor D^2	Int. Dia. D	Factor D^2
14	13.500	182.25	13.125	172.27	12.750	162.60
	13.375	178.89	13.000	169.00	12.500	156.25
	13.250	175.60	12.875	165.77	12.000	144.00
15	14.500	210.25	14.125	199.52	13.750	189.10
	14.375	206.64	14.000	196.00	13.500	182.25
	14.250	203.10	13.875	192.52	13.000	169.00
16	15.500	240.25	15.125	228.77	14.750	217.60
	15.375	236.39	15.000	225.00	14.500	210.25
	15.250	232.60	14.875	221.27	14.000	196.00
17	16.500	272.25	16.125	260.02	15.750	248.10
	16.375	268.14	16.000	256.00	15.500	240.25
	16.250	264.10	15.875	252.02	15.000	225.00
18	17.500	306.25	17.125	293.27	16.750	280.06
	17.375	301.89	17.000	289.00	16.500	272.25
	17.250	297.60	16.875	284.77	16.000	256.00
20			19.125	365.77	18.750	351.60
	19.375	375.39	19.000	361.00	18.500	342.25
	19.250	370.60	18.875	356.27	18.000	324.00
21			20.125	405.02	19.750	390.10
	20.375	415.14	20.000	400.00		
	20.250	410.10	19.875	395.02		
22			21.125	446.27	20.750	430.60
	21.375	456.89	21.000	441.00		
	21.250	451.60	20.875	435.77		
24			23.125	534.77	22.750	517.60
			23.000	529.00		
	23.250	540.60	22.875	523.27		
26			25.125	631.27	24.750	612.60
			25.000	625.00		
	25.250	637.60	24.875	618.77		
28			27.125	735.77	26.750	715.60
			27.000	729.00		
			26.875	722.27		
30			29.125	848.27	28.750	826.60
			29.000	841.00		
			28.875	833.77		

(K_1)—Scale Factor.

K_1 is determined by the water column equivalent of the maximum scale reading on the Manometer, or commercial meter. Numerically, K_1 is equal to the square root of the height in inches of a column of water, which gives the maximum reading on the scale of the meter. The Manometer shown in Fig. 1 may be filled with water for measuring gases. In that case K_1 is equal to 3.00, that is, $\sqrt{9.00}$. When filled with mercury, K_1 is equal to $3.00 \times \sqrt{13.6}$, which makes it 11.07. When measuring steam or water, the Manometer is usually filled with mercury under water and the value of K_1 is equal to $3.00 \times \sqrt{12.6}$, which makes it 10.65. In the case of commercial meters, K_1 is determined in a similar manner by a water column test on the meter.

(K_2)—Density Factor.

K_2 is based on the density of the fluid at the given condition of the flow. The factor K_2 for any given

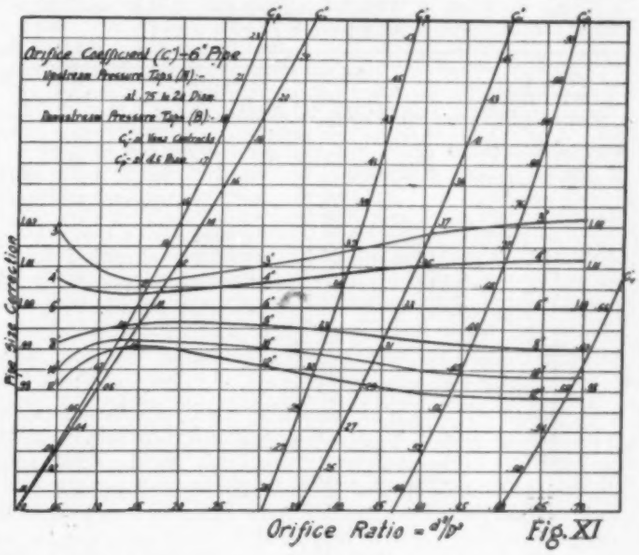


Fig. XI

fluid varies in proportion to the ratio of the square roots of the densities at the respective pressures and temperatures. Table II shows the values of K_2 for saturated steam in pounds per hour corresponding to various pressures of the steam in the line. Table III shows the values of K_2 for water, both in pounds per hour and in gallons per hour, corresponding to various temperatures of the water. Table IV shows the values of K_2 for atmospheric air, corresponding to various pressures. For gases other than air a correction factor is given in Table VII.

TABLE II—(K_2) DENSITY FACTOR FOR STEAM

The numerical value of K_2 for pounds per hour is equal to 3.593 times the square root of the density at the given pressure of the steam.

Gauge Press	K_2	Gauge Press	K_2	Gauge Press	K_2
0	0.6938	45	1.337	170	2.282
1	0.7157	50	1.389	175	2.311
2	0.7373	55	1.438	180	2.340
3	0.7581	60	1.486	185	2.371
4	0.7772	65	1.531	190	2.400
5	0.7962	70	1.575	195	2.428
6	0.8145	75	1.620	200	2.456
7	0.8325	80	1.660	205	2.483
8	0.8501	85	1.702	210	2.510
9	0.8677	90	1.742	215	2.537

TABLE II—(K_2) DENSITY FACTOR FOR STEAM
(Continued)

10	0.8846	95	1.782	220	2.564
11	0.9011	100	1.820	225	2.590
12	0.9173	105	1.857	230	2.616
13	0.9330	110	1.894	235	2.642
14	0.9485	115	1.930	240	2.667
15	0.9640	120	1.965	245	2.692
16	0.9790	125	1.999	250	2.717
17	0.9938	130	2.032	255	2.742
18	1.0085	135	2.065	260	2.767
19	1.0233	140	2.098	265	2.793
20	1.0369	145	2.130	270	2.816
25	1.1028	150	2.162	275	2.841
30	1.1670	155	2.193	280	2.863
35	1.2270	160	2.224	285	2.888
40	1.2834	165	2.254	290	2.913

TABLE III—(K_2) DENSITY FACTOR FOR WATER

The numerical value of K_2 for pounds per hour is equal to 3.593 times the square root of the density at the given temperature of the water. For gallons per hour the value of K_2 is equal to 3.593 $\times$ 7.48 divided by the square root of the density at the given temperature of the water.

deg. F. Temperature,	Lbs. per hour K_2	Gallons per hour K_2
60	28.38	3.405
70	28.37	3.407
80	28.35	3.410
90	28.33	3.413
100	28.30	3.416
110	28.27	3.420
120	28.24	3.424
130	28.20	3.428
140	28.16	3.433
150	28.12	3.438
160	28.07	3.443
170	28.02	3.449
180	27.97	3.455
190	27.92	3.461
200	27.86	3.468
210	27.81	3.475
220	27.76	3.482
230	27.70	3.489
240	27.64	3.497
250	27.58	3.505
260	27.51	3.513
270	27.43	3.521
280	27.35	3.530
290	27.27	3.540

TABLE IV—(K_2) DENSITY FACTORS FOR AIR
Standard Cubic Feet per Hour at 30 and 60

For gas of specific gravity other than unity see correction factor (S).

The numerical value of K_2 for standard cubic feet of air per hour is equal to 47.3 times the square root of the density at the given pressure.

Gauge Pressure, Inches of Water	K_2	Gauge Pressure, Inches of Mercury	K_2	Gauge Pressure, Lbs. per Square In.	K_2
0	13.01	0	13.01	0	13.01
2	13.04	1	13.22	1	13.44
4	13.08	2	13.44	2	13.85
6	13.11	3	13.65	3	14.26
8	13.14	4	13.85	4	14.66
10	13.17	5	14.05	5	15.05
12	13.20	6	14.25	6	15.42
14	13.23	7	14.45	7	15.79
16	13.26	8	14.65	8	16.15
18	13.30	9	14.84	9	16.50
20	13.33	10	15.02	10	16.85
22	12.36	11	15.21	11	17.18
24	13.39	12	15.40	12	17.50
26	13.42	13	15.58	13	17.81
28	13.45	14	15.76	14	18.12
30	13.48	15	15.94	15	18.43
32	13.51	16	16.12	16	18.74
34	13.54	17	16.29	17	19.04
36	13.58	18	16.46	18	19.34
38	13.61	19	16.63	19	19.64
40	13.64	20	16.80	20	19.94
42	13.67	21	16.97	25	21.37
44	13.70	22	17.13	30	22.64
46	13.72	23	17.29	35	23.88
48	13.75	24	17.45	40	25.11
50	13.78	25	17.61	45	26.19
52	13.81	26	17.77	50	27.26
54	13.84	27	17.93	55	28.26
56	13.88	28	18.09	60	29.24
58	13.91	29	18.25	65	30.22
60	13.94	30	18.40	70	31.20

TABLE V—M—CORRECTION FACTOR FOR SUPERHEAT OR QUALITY

M is based upon the ratio of the densities of the fluid at the different qualities or superheat. The numerical value of M is equal to the square root of the ratio of the density at the given quality or superheat, as referred to dry saturated steam.

In most cases the constants for steam are calculated for the dry saturated state so that the correction factor (M) becomes unity.

If the steam contains moisture, a correction should be made to get the actual content of the fluid. Two sets of corrections are given for the quality of the steam. The first under "Steam" shows the net dry steam content of the fluid. The second, under "Total Water," includes the dry steam content plus the entrained moisture.

QUALITY CORRECTION TABLE FOR STEAM

Quality	Correction M Steam	Correction M Total Water
.90	.948	1.055
.91	.954	1.048
.92	.959	1.043
.93	.964	1.038
.94	.969	1.033
.95	.974	1.027
.96	.979	1.022
.97	.984	1.017
.98	.989	1.011
.99	.994	1.006
1.00	1.000	1.000

SUPERHEAT CORRECTION TABLE FOR STEAM

Deg. F. Superheat	Correction M	Superheat Deg. F.	Correction M
0	1.000	130	.907
10	.991	140	.901
20	.982	150	.895
30	.974	160	.890
40	.966	170	.885
50	.958	180	.880
60	.951	190	.875
70	.944	200	.870
80	.937	250	.847
90	.931	300	.826
100	.925	400	.789
110	.919	500	.757
120	.913	600	.731

TABLE VI—(M) CORRECTION FACTOR FOR TEMPERATURE FOR DRY GASES

The numerical value of M is equal to $\sqrt{\frac{460+60}{460+t}}$ where "t" is the temperature of the flowing gas, deg. F.

Temp. Deg. F.	Correction M	Temp. Deg. F.	Correction M	Temp. Deg. F.	Correction M
0	1.063	155	.920	280	.838
10	1.052	160	.916	285	.836
20	1.042	165	.912	290	.833
30	1.030	170	.909	295	.830
40	1.020	175	.905	300	.827
50	1.009	180	.902	350	.802
60	1.000	185	.898	400	.778
65	.996	190	.895	450	.756
70	.991	195	.891	500	.736
75	.986	200	.888	550	.718
80	.981	205	.885	600	.700
85	.977	210	.881	650	.684
90	.972	215	.878	700	.670
95	.968	220	.875	750	.656
100	.964	225	.872	800	.645
105	.959	230	.868	850	.630
110	.956	235	.865	900	.619
115	.951	240	.862	950	.607
120	.947	245	.859	1000	.597
125	.943	250	.856	1050	.587
130	.939	255	.853	1100	.577
135	.935	260	.850	1150	.568
140	.931	265	.847	1200	.560
145	.927	270	.844	1250	.552
150	.923	275	.841	1300	.544

TABLE VII—(S) CORRECTION FACTOR FOR SPECIFIC GRAVITY

The correction factor "S" is applied to gases other than air, or to liquids other than water. The numerical value of "S" is equal to unity (1) divided by the square root of the specific gravity of the fluid.

In the case of liquids multiply by "S" for gallons per hour, or divide by "S" for pounds per hour.

Specific Gravity	Correction S	Specific Gravity	Correction S
0.30	1.826	0.50	1.414
0.31	1.796	0.51	1.400
0.32	1.767	0.52	1.386
0.33	1.741	0.53	1.373
0.34	1.715	0.54	1.361
0.35	1,690	0.55	1.349
0.36	1.666	0.56	1.336
0.37	1.644	0.57	1.324
0.38	1.622	0.58	1.313
0.39	1.601	0.59	1.302
0.40	1.582	0.60	1.291
0.41	1.562	0.61	1.280
0.42	1.543	0.62	1.270
0.43	1.525	0.63	1.260
0.44	1.508	0.64	1.250
0.45	1.491	0.65	1.240
0.46	1.474	0.66	1.230
0.47	1.458	0.67	1.221
0.48	1.443	0.68	1.213
0.49	1.428	0.69	1.204

Specific Gravity	Correction S	Specific Gravity	Correction S	Specific Gravity	Correction S
0.70	1.195	1.00	1.000	1.30	0.877
0.71	1.187	1.01	0.995	1.31	0.874
0.72	1.178	1.02	0.990	1.32	0.871
0.73	1.168	1.03	0.985	1.33	0.867
0.74	1.162	1.04	0.981	1.34	0.864
0.75	1.155	1.05	0.976	1.35	0.861
0.76	1.147	1.06	0.971	1.36	0.857
0.77	1.140	1.07	0.967	1.37	0.854
0.78	1.132	1.08	0.963	1.38	0.851
0.79	1.125	1.09	0.958	1.39	0.848
0.80	1.118	1.10	0.953	1.40	0.845
0.81	1.112	1.11	0.949	1.41	0.842
0.82	1.104	1.12	0.945	1.42	0.839
0.83	1.098	1.13	0.941	1.43	0.836
0.84	1.091	1.14	0.937	1.44	0.833
0.85	1.085	1.15	0.933	1.45	0.830
0.86	1.078	1.16	0.929	1.46	0.828
0.87	1.072	1.17	0.925	1.47	0.825
0.88	1.066	1.18	0.921	1.48	0.822
0.89	1.060	1.19	0.917	1.49	0.819
0.90	1.054	1.20	0.913	1.50	0.817
0.91	1.048	1.21	0.909	1.51	0.814
0.92	1.042	1.22	0.905	1.52	0.811
0.93	1.037	1.23	0.902	1.53	0.809
0.94	1.032	1.24	0.898	1.54	0.806
0.95	1.026	1.25	0.894	1.55	0.803
0.96	1.021	1.26	0.891	1.56	0.801
0.97	1.015	1.27	0.887	1.57	0.798
0.98	1.010	1.28	0.884	1.58	0.796
0.99	1.005	1.29	0.881	1.59	0.793

DISCUSSION

W. N. Flanagan: I haven't very much to say on this subject, as I think Mr. Spitzglass has covered it pretty thoroughly.

There is one point that has come to my attention several times, particularly in measuring water with an orifice, also measuring with a pitot tube. You do not find pipes very regular in size. The pipe, when it left the tube mill, may have measured up pretty well, but due to corrosion and incrustation or pitting the surface becomes very rough and irregular.

I would like to ask Mr. Spitzglass if he has any data on the roughness coefficient of that pipe, or how that will affect the orifice measurement, assuming that the pipe would probably have the same average diameter and average area as when it went in, but due to pitting there are a series of wave-like surfaces on the inside. These would have somewhat the same effect upon the differential reading as if the pressure connections extended into the pipe.

H. C. Siebert: I was very highly interested in Mr. Spitzglass' paper. I might say that he has expressed my views on the subject.

I was particularly interested in his bringing up the accuracy of measurement of variable flow. About 10 years ago, as you know, I had the opportunity to measure the flow of steam under the most variable conditions, namely, for blooming mill reversing engines. In that particular case, we used an orifice type of meter, rather a thick orifice, Hallwachs discs with their Manometer, which was an electrical instrument, a glass tube having a number of platinum contacts fused into it. The rate of the flow deflected the mercury which acted on resistance and which in turn actuated the armature of a recording instrument. For a record of the flow we used the spark recorders made by Siemens and Halske.

We found at that time certain rates or certain quantities of steam per ton of ingots or per ingot. I might say that many measurements have been made since in various plants on engines of similar type by perhaps more refined means, but as far as I have been able to learn, our measurements have checked with those very closely.

I don't know that I can add anything more. I think that the engineers present should be very thankful to Mr. Spitzglass for the interesting presentation of his paper.

W. R. Little: I enjoyed Mr. Spitzglass's paper very much. The point that struck me most was the details on the installation of orifices and methods of running the connecting piping. Too much care cannot be exercised in selecting orifice locations and running the connecting piping. Most troubles are due to faulty installation, and Mr. Spitzglass brought out this point very clearly.

Mr. Spitzglass states that there are two ways to measure the air used for combustion; by analyzing the flue gases leaving the boiler or by measuring the resistance to the flow of gases through the passes. He prefers the former method because the latter is affected by the change in density due to change in temperature of the gases. This is true, but since there is a definite relation between the steaming of a boiler and the increase in temperature of the gases and the quantity of gases passing, the change in density which would tend to affect the differential can be easily compensated. The method of analyzing the flue gas is open to question on account of leakage in the setting, and it is a big problem to know where and how to take samples for analysis. Stratification of the gases enter into it, and you may have as much as 5 per cent variation in CO_2 across a boiler pass under certain conditions.

A. G. Witting: I would like to ask if Mr. Spitzglass has had occasion to try out a flow meter in measuring air or gas delivered through a pipe line from a reciprocating blowing engine or gas booster. I understand that some very elaborate tests were made a couple of years ago and that all kinds of measuring instruments were tried out, but that none proved satisfactory. We tried ourselves to measure the flow of air by means of an orifice plate, but the result left us in doubt as to the accuracy. The influence of eddy currents caused by the pulsations from the engine must obviously somehow be overcome.

I would also like to emphasize what Mr. Little said with regard to waste gases, viz., that we are beginning to understand that it is just as important to record the combustible as the CO_2. A CO_2 recorder alone tells you nothing except that the combustion is faulty; what you want to know is, whether the low percentage of CO_2 is due to surplus air or surplus combustible, and you cannot tell this unless you also have a CO recorder or an oxygen recorder.

J. B. Crane: I simply want to mention the question of getting the amount of coal by volume. While it is true that in a box it would be very easy to get the volume of coal, the matter that Mr. Spitzglass suggests of getting the amount of coal by taking the height of the gate over a chain grate stoker will not give a true measure of the amount of coal on the grate.

In 1918 I had occasion to try to arrive at some figure for that so that we could get the amount of coal that was going to the furnaces where we were using chain grate stokers and small size anthracite coal, and we found that with a given height of grate, the amount of coal going through that opening was not a continuous quantity, that is, it varied with the size of coal, and with the wetness of the coal.

Later, I had occasion to try and arrive at a similar conclusion on a speed of underfed stoker with retorts, to try and get some relation between the speed of the stoker and the amount of coal fed to the stoker, and we found there that we could not get any reliable ratio, because with a given revolution of the stoker the amount of coal fed did not always measure uniformly; that it varied with the size of coal and the physical characteristics of the coal. We were unable to get any ratio there that could be used in actual practice.

A. Steed: I was very much interested in Mr. Spitzglass' paper and have nothing to add that will be of special value except that I have had occasion to check up the weight and volume of coal of various sizes.

A check was made on the displacement of the rams on an underfeed stoker to determine if the revolutions of the crank would give an accurate figure for obtaining the amount of coal fed to the furnace. It was found that the weight of the coal displaced (coal as received from crusher) varied as much as 15 per cent when using lump 1½ in. to 3 in. as to the weight when using coal under one inch. This according to Mr. Spitzglass was due to the moisture content of the coal.

A check was made by taking a box of one cubic foot contents and weighing out samples of various sized coal. A large sample of Bituminous was picked out of the stoker hoppers and the box filled with lumps varying from 1 in. to 3 in. and this sample of one cubic foot weighed 42¼ pounds. This same sample was then crushed so that the size ran from ½ in. to 1½ in. lumps with some fines, and the sample put back into the box. It now occupied but 90.5 per cent of the original volume, with a corresponding weight of 46.6 lbs. per cubic foot. This same sample was again crushed so that no lumps were over ½ in. in size and placed in the box. It now occupied 86.5 per cent of its original volume which corresponds to a weight of 48¾ lbs. per cubic foot.

The original sample was used throughout each set of tests so that the moisture content did not vary perceptably. The sample was crushed in an iron box so there was practically no loss from dusting.

J. M. Spitzglass: I will take up these points in their order.

Mr. Flanagan wanted to know what would be the effect of scale, or pitting of the piping, on the accuracy of the orifice. That brings out a very important difference between the use of an orifice and a pitot tube. It is just the difference between the short arm and the long arm of a lever. The orifice is affected by the pipe at some distance away from the opening. The pitting may cause a little additional friction that will reduce the flow there, but as was shown by the figure, the lines of flow will come around and through the orifice, so that the pitting of the pipe will affect the result only in proportion to the factor for the velocity of approach.

The change of the pipe area produced by considerable scaling may affect the results much more because the change in the pipe area changes the ratio of the orifice with a corresponding change in the coefficient of discharge. It will take considerable time before any effect is produced by scaling in the pipe, and the smaller the orifice ratio, the longer the time before the effect becomes serious.

For example, take the case of a 10-inch pipe with a 5-inch orifice. The stream goes through a 5-inch

diameter circle, or an area of 25 circular inches. The approaching stream is 10 inches in diameter or 100 circular inches in area. Accordingly the velocity of approach is one-quarter of the velocity through the orifice. The corresponding differential pressure is one-sixteenth, that is, the effect of the velocity of approach is only one-sixteenth of the whole. Suppose the pipe does scale up, it only affects that one-sixteenth. It may become one-sixteenth plus, but it will be a long time before it will represent 1 per cent on the actual area of the orifice. That is one of the advantages of using an orifice.

The result in the case of a venturi tube is entirely different, as the scale lodges right in the throat where it makes trouble.

I am always fond of telling the story of the fellow who had this trouble with his venturi. He reamed out the throat and then had no further trouble, and the efficiency increased, too.

Mr. Seibert asked about fluctuating flow. I do not think there are any remarks I can make on that. I am glad to know that they did come out as good as they did. If you have a fluctuating flow of steam you should investigate the condition of the reservoirs at the time. If during the fluctuation the pipe becomes very hot at one end, then the results may be off somewhat because there is too much movement of the mercury in the element. The result is a reduction of the column first on one side and then on the other. It may equalize itself on the long run, but it is better to eliminate it as much as possible.

I could write another paper on the subject of the second part as brought out by Mr. Little, especially if I were to include the comments of the other gentleman who said that a CO_2 recorder is a waste of money. I will, however, make an attempt to cover the points in a few words.

The chances are that the gases are pretty well mixed in the boiler. If they were not, something is wrong with the setting, because the object is to maintain the setting so that the gases do mix thoroughly.

The gases should all be formed in the combustion chamber. They should be thoroughly mixed by turning in the first, second and third process and so on to the boiler outlet. I do not believe that at any reasonable distance from the wall you will find a 5 per cent variation in the CO_2. If there is a greater variation then something is wrong with the boiler.

The differential drop through the boiler is not an indication that certain conditions are maintained. We should not overlook the fact that the fireman has a way to help himself by speeding up the grate. For instance, he sees that the air flow according to the differential has increased—it is, say, more than the steam flow. It means to him that there is an excess of air. It might happen by some air coming in and not producing combustion. He does not know that. According to his assumption and based on the meter, air is coming in in a larger quantity than is required. He must stop it, so he chokes the damper.

This, of course, reduces the flow of steam also, but instead of going around looking for the trouble, he will speed up the grates and get more coal to produce the necessary amount of steam. The condition will be worse instead of better, unless he goes around and looks for the trouble, which he is not liable to do.

The measurement of CO is not so important, because CO begins to appear only after 16 per cent of CO_2 in the gases. In general practice, it is a long ways before 16 per cent CO_2 in the flue gases is obtained.

The objection to the CO_2 recorder is the trouble connected with its use. It must be given reasonable attention or it will not operate continuously. With proper attention the instrument will give a positive check on combustion.

The measurement of pulsating flow is a difficult subject. In short, the pulsations must be eliminated before the flow can be measured accurately. The best way to eliminate pulsations is to remove the harmonic action by additional restrictions and a considerable enlargement in the line.

If you have, say, a 4-inch line, widen it out for a distance of 10 or 15 feet, to 10 inches. Then put a restriction there and it may kill the pulsation in the line.

About the measurement of coal. I would like to ask Mr. Crane a question. Did he measure the volume or the weight of the coal?

J. B. Crane: We weighed the coal going in.

J. M. Spitzglass: I was very careful to tell you that weight has nothing to do with the measurement, that it is all volume rather than the weight of dry coal and not the weight of the coal as fired.

J. B. Crane: We weighed the coal before it went into the hopper. Then we took the height of the gate and we could get no steady relationship between the weight going into the hopper and the height of the gate.

J. M. Spitzglass: There is another thing, the human element in getting the height of the gate. An error of ¼ inch in the measurement of the height will make 4 per cent on a height of 6 inches. The coal meter shows the relation automatically without the actual measurement of the height.

J. B. Crane: The depth of the coal at the grate will be at one time 7 inches, and another time 7½ inches, and other times 6½ inches with the same opening of the gate. I mean, with a constant speed, but with a variation in the size of the coal.

J. M. Spitzglass: This is quite possible when the kind of coal, not necessarily the size, is changed. But as long as the same kind of coal is used, accurate results will be obtained in the measurement. When the kind of coal is changed, another calibration is necessary to obtain the constant of the coal meter.

J. B. Crane: Can you get a Btu. per volume so that you have some measure of the efficiency of your boiler?

J. M. Spitzglass: That could be done. The heat value is a factor of the dry coal rather than the wet coal for a given kind.

A. R. Steed: If you take a cubic foot of coal that will pass through a 2-inch screen, dry coal, and then you take a cubic foot of dry coal of the same coal that is slack, will they weigh the same?

J. M. Spitzglass: Yes, they will. If the coal is of the same density the weight will be the same for any size of the lumps.

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The Prevention of Scale Formation by Boiler Water Conditioning[1]

By R. E. HALL,[2] CARL FISCHER[3] and GEORGE W. SMITH[4]

INTRODUCTION

DURING the past two and a half years an investigation into the mechanism of scale formation in boilers and boiler-water conditioning has been carried on by the Bureau of Mines in co-operation with the Hagan Corporation of Pittsburgh, Pa., In addition to a large amount of experimental work in the laboratories of the Bureau, and incidental observations on many boilers, plant tests on boilers under operating conditions have been made as follows: (1) A 42-day test on a 545-hp. Heine boiler, using Monongahela River water without treatment; (2) a 72-day test on 1,000-hp. Stirling boiler, using water high in bicarbonate; (3) a 90-day test on 500-hp. Erie City boilers using Ohio River water treated partly with Dearborn Chemical Company's compound and partly with soda ash; (4) a 50-day test on 1,000-hp. Babcock-Wilcox boiler, using Ohio River water and lime-soda ash treatment; and (5) a test beginning on November 20, 1923, and continuing until the present time, on the boiler mentioned in (1), using soda-ash internal treatment, regulated on the basis of the sulphate concentration of the boiler water.[5] The essential conditions as determined by these investigations which must be maintained in boiler waters to inhibit the formation of hard adherent scale on the heating surfaces will be considered in Part I,[6] and the results ensuing in practice from the maintenance of such conditions will be discussed in Part II (test 5).

PART I—BOILER-WATER CONDITIONING

The primary product of a boiler is dry steam continuously delivered, and in order that this condition may be fulfilled there are three phases relating to the boiler water, which must be continuously controlled; these are as follows: (A) The conditioning of the boiler water so that its evaporation will not result in the deposition of hard, adherent scale, the poor heat conductivity of which interferes with the operation of the boiler, especially at high rating, and results in sagging and leaky tubes. Such conditioning is based entirely on the sulphate concentration and pressure of the boiler water; it is purely a chemical function, and must be clearly differentiated from the other two phases. (B) The removal of the precipitated sludge and suspended insoluble matter which results from the chemical phase of conditioning, and from the evaporation of the water. This phase is entirely mechanical. (C) The prevention of boiler water being removed from the boiler in the form of tiny droplets entrained in the steam—in other words, the prevention of moisture in the steam. Chemical means may be used in alleviating this condition to a certain extent, but after all, such means merely temporize with the condition. It is advisable to consider this phase mechanical also, and use mechanical means in controlling it.

A. THE PREVENTION OF ADHERENT SCALE FORMATION.

Results Without and With Conditioning.

The results ensuing from evaporating Monongahela River water in a boiler with no conditioning, and with conditioning based on the sulphate concentration in the boiler water, are illustrated by Fig. 1. *A* and *B* are sections of a tube taken from the second row of tubes of No. 3 boiler, after the evaporation of 41 million pounds of water with no conditioning; *C* and *D* are sections of a tube taken from the first row of tubes of No. 2 boiler, after the evaporation of 36.4 million pounds of water, conditioned according to the sulphate concentration in the boiler water. The scale on *A* and *B* is composed almost entirely of anhydrite, while the film on *C* and *D* is largely calcium carbonate. The most common type of hard adherent scale is that composed largely of anhydrite; other types are those which contain a considerable quantity of magnesium hydroxide and magnesium silicate. Fortunately, the conditions which inhibit the formation of anhydrite scale prevent the growth of other types of scale as well.

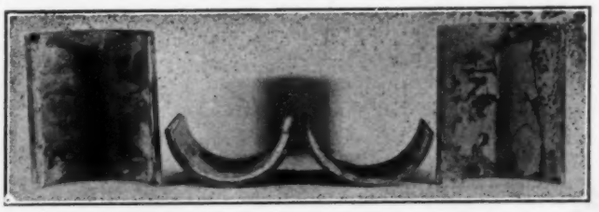

FIG. 1.—*Sections of tubes from No. 3 and No. 2 boilers. A and B, without treatment, from boiler No. 3; C and D, with treatment, from boiler No. 2.*

Sulphate Determination.

The amount of chemical necessary to condition the boiler water properly depends upon the concentration of sulphate radical in the boiler water and the pressure at which the boiler is operated. Simple equipment, suitable for the rapid determination of sulphate in the boiler room, is shown in Fig. 2. A sample of water is drawn from the boiler, preferably through a cooling spiral,[7] and filtered

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[1]Published by permission of the Director, U. S. Bureau of Mines.

[2]Physical chemist, Pittsburgh Experiment Station, U. S. Bureau of Mines.

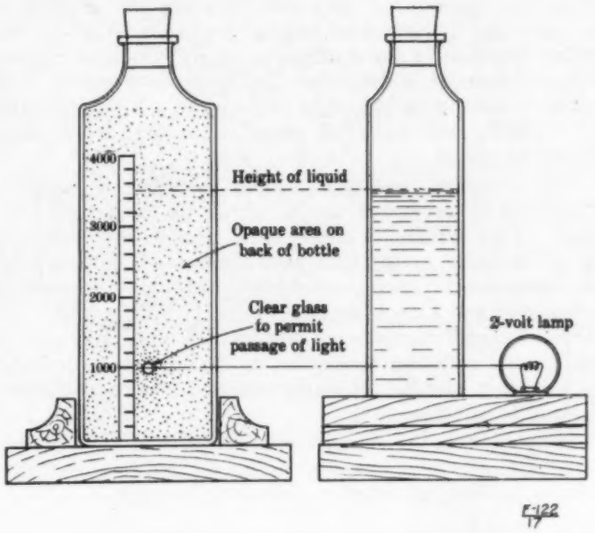
[3]Superintendent of heat, light and power, Mesta Machine Company, Homestead, Pa.

[4]Chemical engineer, Hagan Corporation, Pittsburgh, Pa.

[5]The co-operation of Messrs. Carl Fischer, Mesta Machine Company, co-author in this paper; L. E. Harkinson, West Penn Power Company, and C. L. Dudley, Jones & Laughlin Steel Corporation, in these investigations has made possible the correlation of laboratory and plant data.

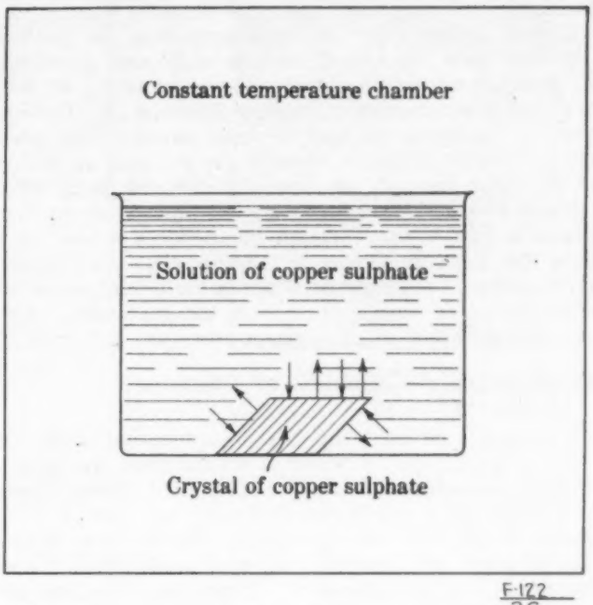
[6]No consideration will be given in this article to the factors underlying the deposition of soft adherent carbonate scale in the feed-water pipes leading to the boiler. The reader is referred to "Boiler-Water Treatment from the Standpoint of Chemical Equilibrium", by R. E. Hall, G. W. Smith and H. A. Jackson, published in the Proceedings of the National Electric Light Association, 1924, for a discussion of this type of scale.

[7]The error involved in not using a cooling spiral is discussed in "Simple Apparatus for the Control of Boiler Water Conditioning Based on Chemical Equilibrium", by R. E. Hall, to be published in Jour. Ind. Eng. Chem.



Apparatus for determining sulphate in boiler water.

FIG. 2.



The dynamic condition of saturation equilibrium

FIG. 4.

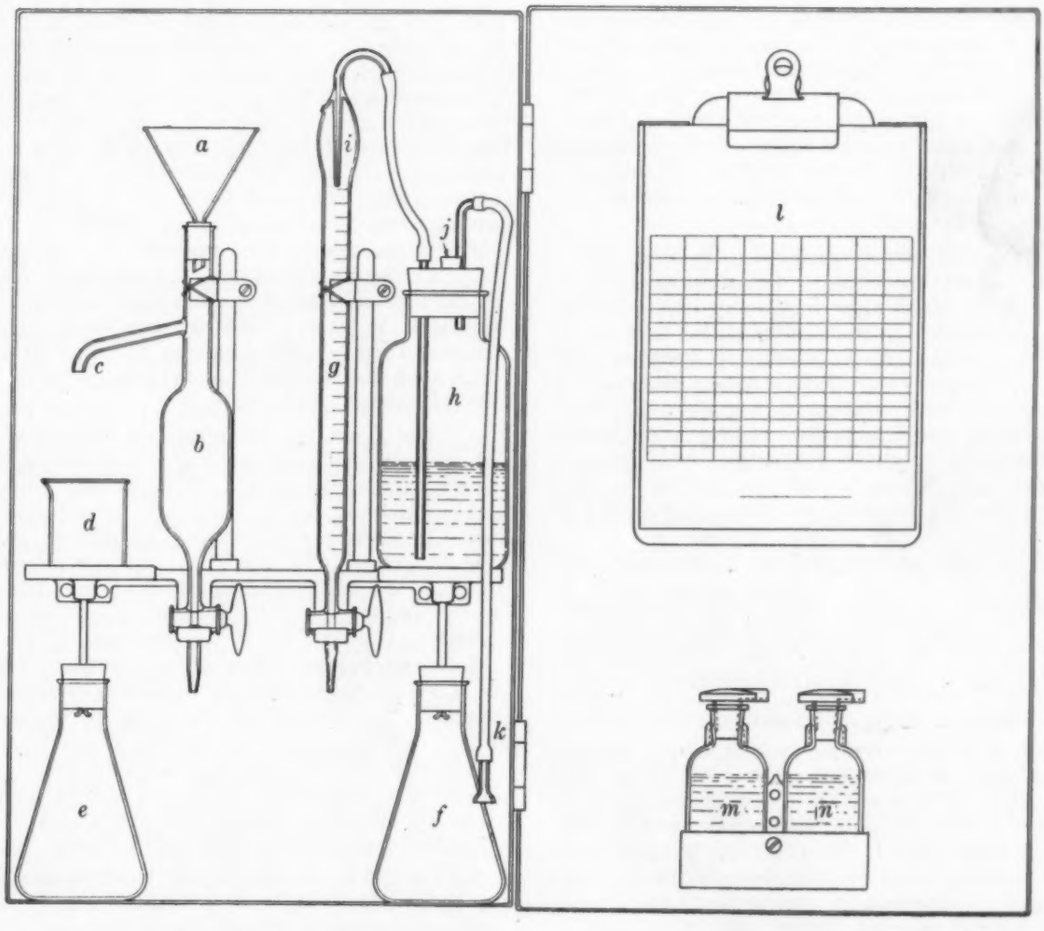


FIG. 3.—*Apparatus for determining hydroxyl and carbonate or phosphate concentration.*

immediately. A measured quantity (usually 10 c.c.) of the filtered boiler water is introduced into the bottle, which has been blackened on one side and provided with graduations on the other. Approximately 10 c.c. of a 5 per cent solution of barium chloride, N/10 with respect to hydrochloric acid, is next added. The precipitated barium sulphate renders the solution so milky that the light can not be seen through the peep-hole. If distilled water be added, a time comes when the filament is just visible through the milky solution. Of course the solution should be shaken after each addition of water. The height of water in the bottle, when the filament becomes visible, read from the graduated scale, is the concentration of sulphate in parts per million.

Determination of Carbonate or Phosphate Concentration.

The apparatus used for this determination is shown in Fig. 3. A sample of water is drawn from the boiler, preferably as mentioned above, and filtered through funnel *a* into pipette *b*, which overflows through *c* into *d* when it contains 100 c.c. The sample is drawn from *b* into *e*, and titrated with burette *g*,using phenolphthalein and bromphenol blue as indicators. From the titrations the amount of carbonate or phosphate radical already in the boiler water is known.

A knowledge of the sulphate and carbonate or sulphate and phosphate concentration in the boiler water, in conjunction with curves which we have established showing the proper relation of carbonate or phosphate to sulphate concentration, is all that is necessary to operate a boiler with no growth of hard adherent scale on the heating surfaces. There is no need for any feed-water analysis, other than to test it for acidity with bromphenol blue now and then, merely to forestall any corrosive action on feed-water pipes due to acidity. The required carbonate or phosphate may be introduced into the feed water or directly into the boiler. *It is absolutely essetial, however, that the proper relation of sulphate to carbonate or phosphate concentration be maintained at all times in the boiler water.*

By this method of conditioning, for the first time, definite limits are established as to the amounts of carbonate or phosphate which must be present in the boiler water. Also, while the concentration of sulphate in a water has little bearing on treatment, so long as the water is used for laundry or other purposes not involving boiler pressures and temperatures, under the conditions of temperature and pressure existing in the modern boiler plant, the sulphate concentration is all-important.

THE PROPER RATIO OF CARBONATE TO SULPHATE CONCENTRATION IN BOILER WATERS

Let us turn now to a consideration of the equilibrium conditions in saturated solutions, and from the relations found therin establish the proper ratios of carbonate to sulphate concentration under various conditions.

The Equilibrium in a Saturated Solution.

If a crystal of copper sulphate be placed in a beaker of water in a constant temperature chamber (Fig. 4), molecules of copper sulphate leave the crystal and move into the water. They continue in motion, and if the beaker remain undisturbed, its contents become uniformly blue, showing uniform distribution throughout. Some molecules are continually leaving the crystal and moving out into the solution, while other molecules in the solution impinge upon the crystal and remain there. This condition of motion is depicted in the figure by the arrows pointing toward and away from the crystal. When the number of molecules leaving the crystal is the same as the number impinging on it, there is no further increase in the concentration of dissolved copper sulphate, and the solution is said to be saturated. The crystal is said to be the solid phase, and the solution the liquid phase, and the solid phase is in equilibrium with the liquid phase.

The solution readily conducts the electric current, copper being deposited as metal at the negative electrode. This occurs because some of the molecules of copper sulphate in solution have dissociated into a positive component (copper positively charged, represented by Cu^{++}), and a negative component (sulphate SO_4^{--}). These charged components are called ions, and are in equilibrium with the molecules, so that at any time there are a certain number of molecules and a certain number of ions in solution.

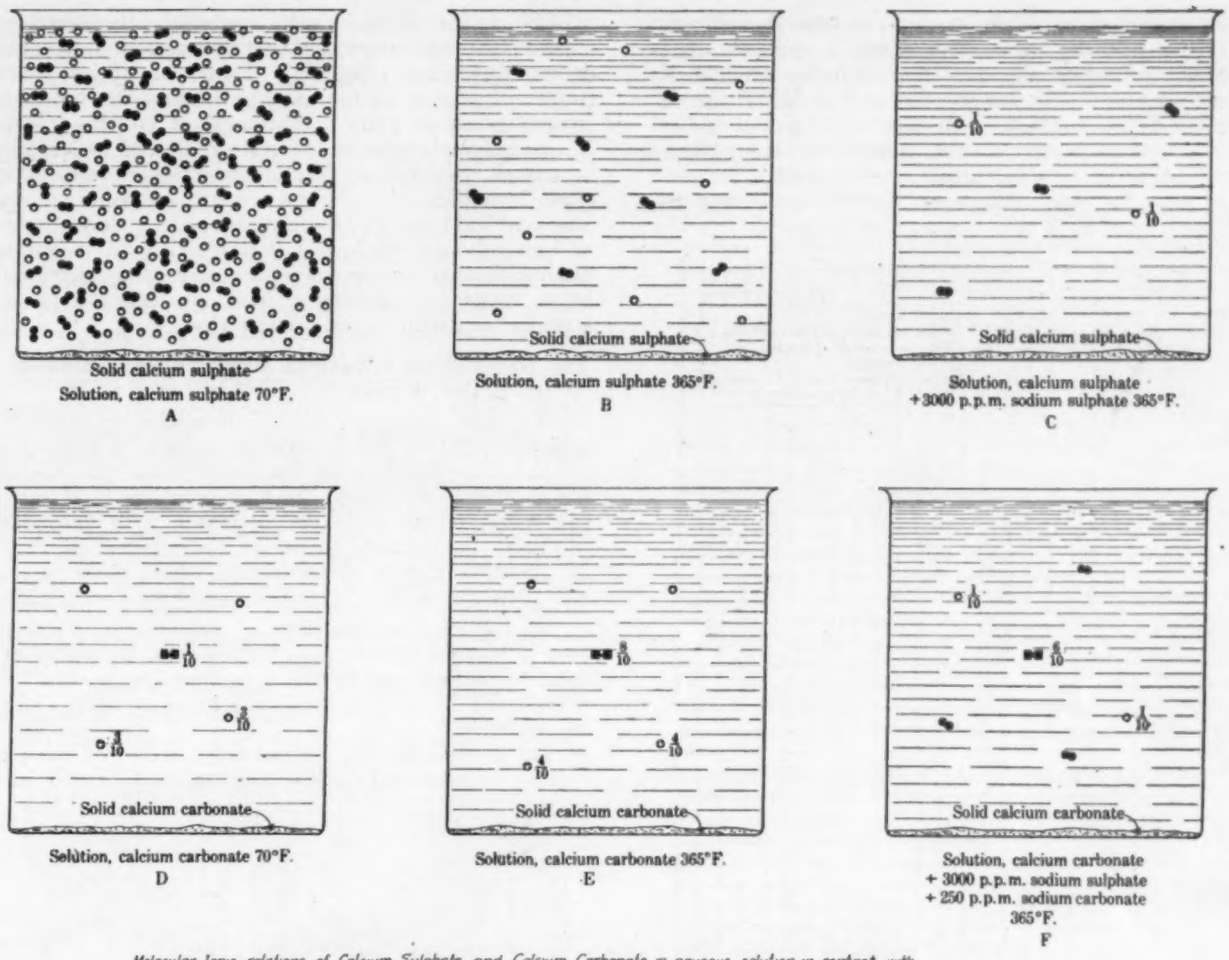
What is true of copper sulphate is also true of calcium sulphate and sodium chloride and sodium carbonate; in fact, all salts and acids and bases.

Calcium Sulphate and Calcium Carbonate.

Suppose that we have a vessel 100 cm. by 100 cm. by 10 cm., containing a solution of calcium sulphate in equilibrium with its solid phase at 70 deg. F. Then if all the molecules and ions present in solution at any instant are represented on a plane surface, the result is *A* of Fig. 5, in which each pair of solid circles represents 1 gram of molecular calcium sulphate, and each two open circles represent 1 gram of calcium sulphate ions. If the temperature of this solution be raised now to 365 deg. F., the condition shown in *B* exists; and whereas under the conditions of *A* it took 94 grams of molecules and 106 grams of ions to saturate the solution, under those of *B* it takes but 7 grams of molecules and 5 grams of ions for saturation. The ions of calcium sulphate are Ca^{++} and SO_4^{--}; those of sodium sulphate are $2Na^{+}$ and SO_4^{--}. If to the solution of *B* we add sodium sulphate to the amount of 3,000 p.p.m., thereby increasing the amount of the common ion, SO_4^{--}, the conditions of *C* are obtained. Only 3 grams of calcium sulphate molecules and 0.2 grams of calcium sulphate ions are present at saturation; increasing the concentration of the common SO_4^{--} ion has greatly decreased the amount of calcium sulphate present in the solution at saturation.

D and *E* of Fig. 5 represent the saturation equilibrium of calcium carbonate at 70 deg. and 365 deg. F., respectively. Calcium carbonate is much less soluble than calcium sulphate at 70 deg., but its solubility increases with increase in temperature, so that at 365 deg. it is not so greatly different from that of calcium sulphate. If to *E* we add sodium carbonate and sodium sulphate to the amount of 250 and 3,000 p.p.m., respectively, the conditions shown in *F* are obtained. The amount of calcium carbonate molecules and ions has been decreased because we have added the common carbonate ion. But there have appeared in the solution molecules of calcium sulphate, equal in amount to those of *C* above; in fact, if we were to add 4,000 p.p.m. of sodium sulphate to *F* instead of 3,000, we would find crystals of calcium sulphate precipitating from the solution, and crystals of calcium carbonate dissolving.

The condition existing in boiler waters are similar to those which we have just discussed. The raw water contains calcium sulphate molecules and ions. If it is evaporated without conditioning, the cycle of changes



Molecular Ionic relations of Calcium Sulphate and Calcium Carbonate in aqueous solution in contact with the solid phase, under different conditions

FIG. 5.

shown in *A, B,* and *C* occurs, and solid calcium sulphate is deposited on the heating surfaces. On the other hand, evaporation of water to which sodium carbonate has been added leads to the condition of *F,* and the amount of sodium carbonate must be sufficient so that saturation with calcium sulphate will never occur.

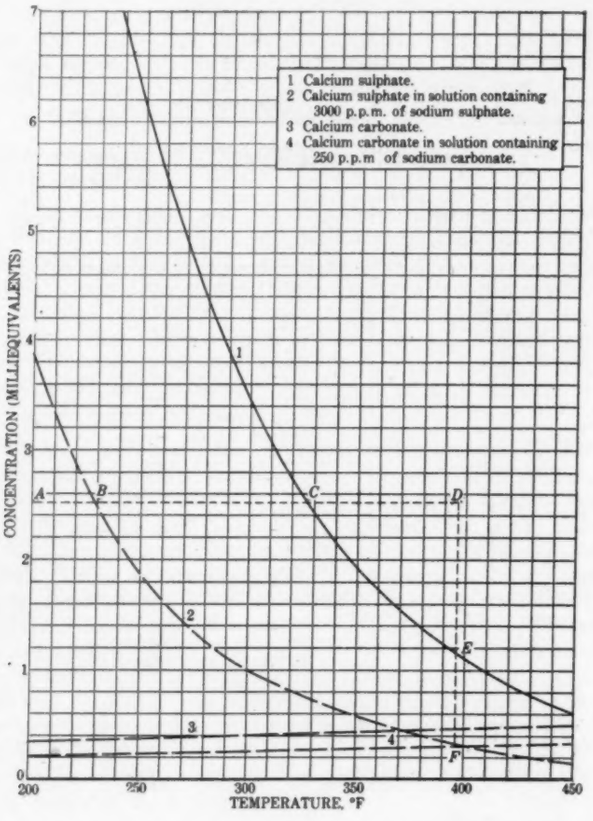
Instead of using diagrams, such as those just discussed, for representing saturation equilibrium, it is simpler to use curves such as those of Fig. 6, in which the vertical axis represents concentration in solution, and the horizontal axis the temperature. (The vertical axis is in milliequivalents; to change to parts per million—for calcium sulphate, multiply by 68; and for calcium carbonate, by 50.) Thus curves 1 and 3 represent the solubility of calcium sulphate and calcium carbonate, respectively, over the temperature range 200 to 450 deg. F., and curves 2 and 4 their solubility over the same temperature range, in the presence of sodium sulphate and sodium carbonate, respectively. If a water containing no sodium sulphate and an amount of calcium sulphate equivalent to *A* (Fig. 6), or 171 p.p.m., is gradually heated, no separation of calcium sulphate crystals occurs until the point *C,* 328 deg. F., is reached. From that point on, as the temperature is raised, separation of crystals continues, and when *D* is reached, 396 deg. F., the amount of crystals which has separated is *DE,* or 92 pounds for every million pounds of water heated. On the other hand, if the water originally contained 3,000 p.p.m. of sodium sulphate in addition to its 171 p.p.m. of calcium sulphate, separation of crystals of calcium sulphate begins at *B,* 228 deg. F.; and when the temperature has been raised to *D,* 396 deg. F., the amount of crystals which has separated, is *DF,* or 151 pounds per million pounds of water heated. It should be noted in particular how with temperature increase the solubility of calcium sulphate decreases and that of calcium carbonate increases.

The Mechanism of Scale Formation on the Heating Surfaces.

What is the relation between the solubility curves of calcium sulphate and calcium carbonate, and the prevention of growth of adherent scale on the heating surfaces of the boiler? This question is best answered by observations made with the experimental boiler shown in Fig. 7. Feed water is introduced at *a,* and *g* is a heating element made of nichrome ribbon, and corresponds to the heating surfaces of a boiler. Circulation takes place in the direction of the arrows, and is rapid. The filter *b* corresponds to the de-concentrator shown attached to the boiler in Fig. 14. The steam outlet is *h.*

If a solution of calcium sulphate is evaporated in this boiler, practically all of the solid phase which precipi-

tates is deposited as adherent scale on the hot ribbon. A little consideration shows that this is exactly what might be expected to happen. The solubility of calcium sulphate decreases with temperature at 212 deg. F; hence its point of least solubility in the experimental boiler is in the film of water in contact with the hot ribbon, and if separation of solid phase occurs at all, it is certain to take place at this point. If this reasoning be



Solubility of Calcium Sulphate and Calcium Carbonate in aqueous solution and in the presence of Sodium Sulphate and Sodium Carbonate, respectively

FIG. 6

correct, then solutions of calcium hydroxide and calcium chromate, upon evaporation, should deposit their solid phase on the metal heating unit; and solutions of calcium iodate and potassium sulphate should precipitate their solid phases on the cooler glass surfaces, or in the cooler sections of the solution, for the solubility of calcium hydroxide and calcium chromate decreases with temperature increase (Fig. 8), and that of the calcium iodate and of potassium sulphate increases with temperature increase. The experiments have borne out the theory in every instance. The hydroxide and chromate form adherent scale, but the iodate and potassium sulphate do not. Further, and this is a crucial test, if a solution of calcium sulphate is evaporated at diminished pressure, so that the temperature of evaporation does not exceed 35 deg. C., it should not deposit as adherent scale on the heating element, but on the glass surfaces and throughout the solution. For, as shown in Fig. 8, from 0 to 35 deg. C., the solubility of calcium sulphate increases with temperature increase. Here again experiment completely confirms theory, as practically no adherent scale forms on the nichrome ribbon.

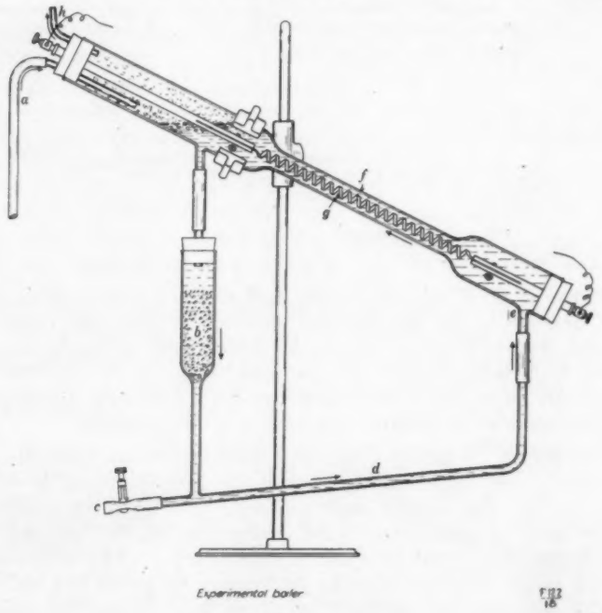
The solubility of calcium carbonate increases with increase of temperature, and that of magnesium hydroxide decreases slightly (Fig. 8). Their solubilities are too slight for testing in the experimental boiler, but observations taken on plant operation show conclusively that if enough carbonate is maintained in the boiler water to ensure the precipitation of the calcium salts as calcium carbonate, there is no growth of adherent scale. The hydroxyl concentration developed by decomposition of the carbonate so lowers the solubility of magnesium hydroxide that its concentration in properly conditioned boiler water is vanishingly small, and hence it becomes a negligible factor in the growth of scale.

The Ratio of Carbonate to Sulphate Concentration in Boiler Waters.

We have shown that the prevention of growth of adherent scale on the heating surfaces of a boiler is assured by so conditioning the boiler water that the solid phase which precipitates is a material such as calcium carbonate, whose solubility increases with temperature increase. It remains to derive the amount of carbonate or other radical concentration which must be maintained in the boiler for various sulphate concentrations.

In Fig. 9, the logarithm of calcium ion concentration is plotted against temperature, the logarithm being used to prevent the curves corresponding to small concentrations from lying so closely together as to be indistinguishable.

Let us consider the intersecting point *A* of the curves "Ca^{++} in saturated $CaSO_4$ solution" and "Ca^{++} in sat-



Experimental boiler

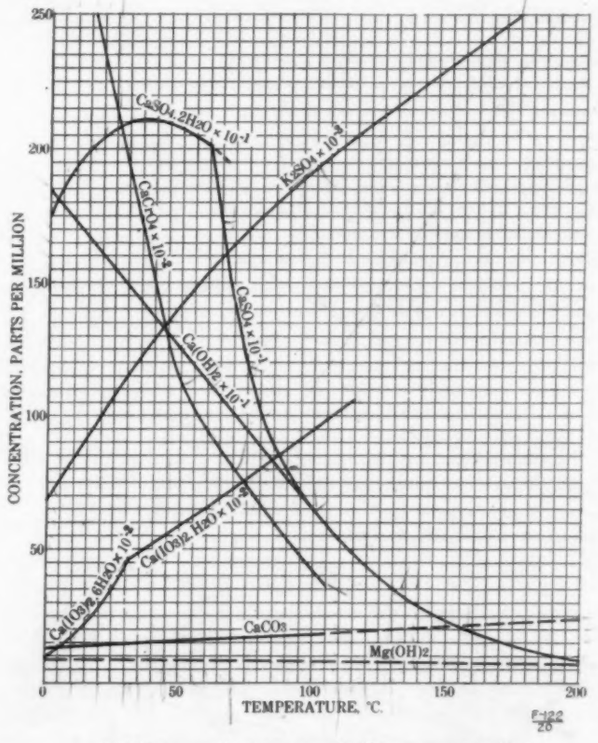
FIG. 7.

urated $CaCO_3$ solution". The solid phase in equilibrium with the former curve is calcium sulphate, while that in equilirbium with the latter is calcium carbonate. Hence at the intersection, where the Ca^{++} concentration is the same for both curves, both calcium sulphate and calcium carbonate will be present in the solid phase. To the left of *A* in solutions containing only calcium sulphate and carbonate, calcium carbonate alone is the stable solid phase, because it is in equilibrium with a smaller value of Ca^{++} than is calcium sulphate. To the right of *A*, however, calcium sulphate is the stable solid phase, because on this side of the intersection it

is in equilibrium with a smaller value of Ca^{++} than is calcium carbonate.

Now *B* and *C* of Fig. 5, and curves 1 and 2 of Fig. 6, show that the presence in solution of a substance with a common ion, such as sodium sulphate, lowers the solubility of calcium sulphate quite markedly. This is shown in Fig. 9 by the very different position of the curve designated "Ca^{++} when SO_4 radical is 2,000 p.p.m.". But with this amount of sulphate ion present the intersection with the calcium carbonate curve is no longer at *A*, but has moved to the left so far that it no longer appears on the diagram. However, if an increase in sulphate ion concentration decreases the solubility of calcium sulphate, likewise an increase in carbonate ion concentration must decrease the solubility of calcium carbonate. That this is true is evidenced by the position of the curve "Ca^{++} when CO_3 radical is 150 p.p.m." Under these conditions, the intersection of the curves is at *D;* to the left of *D,* calcium carbonate is the stable phase in equilibrium with the solution; and to the right of *D,* calcium sulphate is the stable phase. It is apparent that the intersection point *D* may be moved in either direction, at will; to the left by increasing the amount of sulphate, or decreasing the amount of carbonate; to the right by decreasing the amount of sulphate, or increasing the amount of carbonate.

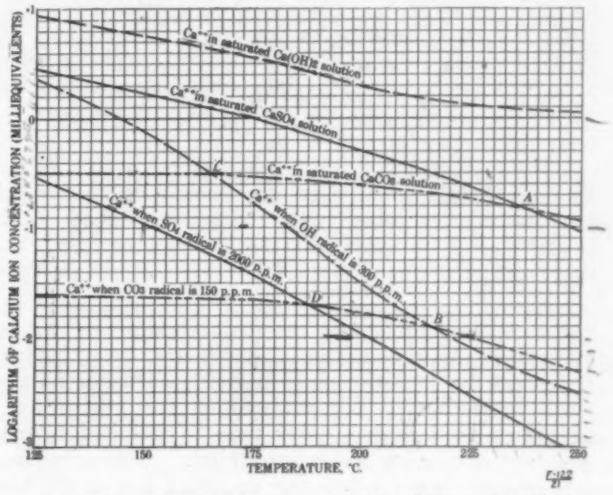
It has been shown that if calcium sulphate is the solid phase in equilibrium with the boiler water, a hard, adherent sulphate scale grows on the heating surfaces;



Solubility curves of substances used in the experimental boiler

FIG. 8.

and that if calcium carbonate is the solid phase in equilibrium, only non-adherent, suspended material may be present. The criterion for conditioning boiler waters, therefore, is to adjust the carbonate and sulphate concentrations so that any intersection such as *D* lies at a temperature (or pressure) higher than that at which the boiler is operating. Thus *D,* as shown in Fig. 9, corresponds to a pressure slightly greater than 150 lbs. gage (185 deg. C.); hence for this pressure, 150 p.p.m. of carbonate is sufficient when the sulphate concentration is 2,000 p.p.m. If the boiler is operating at 210 lbs. pressure (200 deg. C.), 150 p.p.m. of carbonate is no longer sufficient, and enough sodium carbonate must be added to force the carbonate curve down until the intersection lies to the right of 200 deg. C. Likewise, if the sulphate concentration is greater than 2,000


LOGARITHM OF CALCIUM ION CONCENTRATION (MILLIEQUIVALENTS)
TEMPERATURE, °C.
Ca++ in saturated Ca(OH)2 solution
Ca++ in saturated CaSO4 solution
Ca++ in saturated CaCO3 solution
Ca++ when SO4 radical is 2000 p.p.m.
Ca++ when OH radical is 300 p.p.m.
Ca++ when CO3 radical is 150 p.p.m.
A
B
D

Saturation concentrations of calcium ion for the pure salts, and when the sulphate hydrate and carbonate radical concentration is varied. The calculations are based on the constancy of the solubility product

FIG. 9.

p.p.m., 150 p.p.m. of carbonate is no longer sufficient to condition the water for operation at 150 lbs. pressure, but its amount must be increased.

So far we have discussed the adjustment of an intersection such as *D* by the addition of sufficient carbonate. Theoretically, it is just as simple to make the adjustment by removing the sulphate radical with barium salts, thus raising the sulphate curve, and moving the intersection to the right. The amount of sulphates to be removed, however, and the cost of barium salts, are obstacles in conditioning by this method. On the whole, for boilers operating at or below 210 lbs. pressure, adjustment by carbonate seems most satisfactory. Above that pressure it is advisable to use sodium phosphate in the adjustment, because of the rapidity with which sodium carbonate decomposes to form caustic soda. The principles involved in this adjustment are the same as those for carbonate, and will not be discussed here.

In Fig. 8 it is seen that the solubility of calcium hydroxide decreases rapidly with temperature increase, hence it must be classed with the adherent scale-forming materials. In Fig. 9 the curves "Ca^{++} in saturated $Ca(OH)_2$ solution" and "Ca^{++} when OH radical is 300 p.p.m." show that the concentration of hydroxyl (or caustic soda) need not be markedly high to make calcium hydroxide the solid phase in equilibrium in preference to calcium carbonate, and hence induce formation of adherent scale. It is quite probable that the thin film which so frequently forms on the heating surfaces with carbonate conditioning is deposited as adherent calcium hydroxide, and is later changed to the carbonate which we always find upon analysis. It is apparent that the hydroxyl concentration must not be allowed to increase beyond certain limits, and the fallacy of introducing caustic soda into a boiler is self-evident.

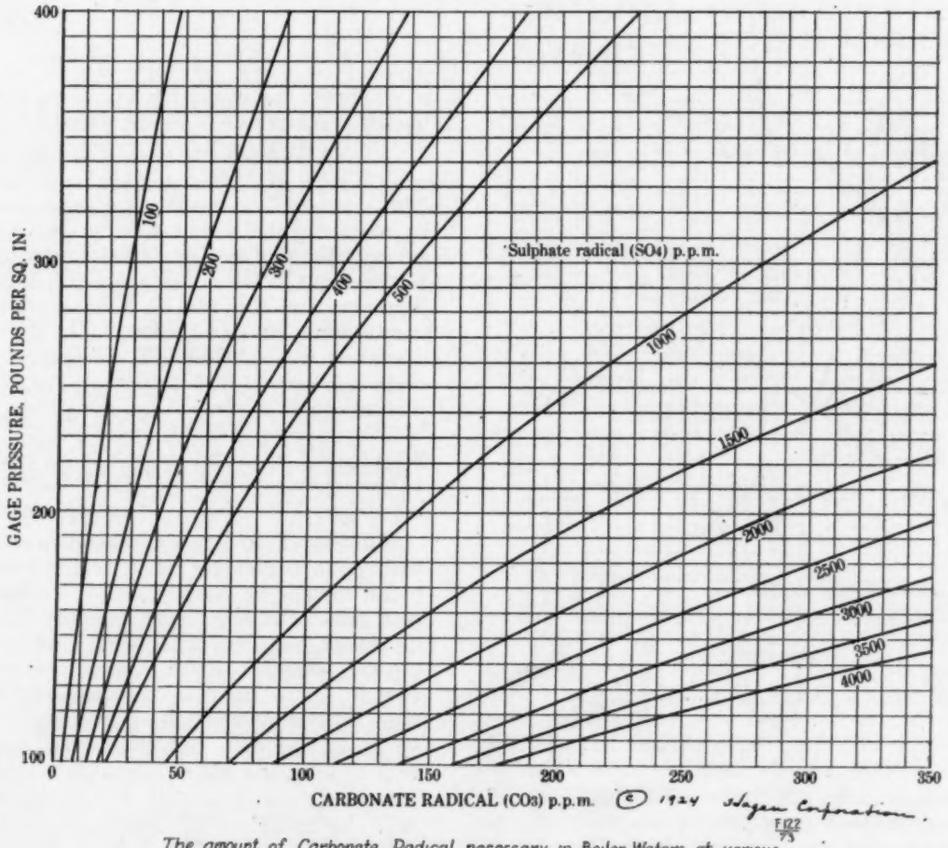
The proper conditioning of a boiler water necessitates that the intersection of the calcium carbonate (or phosphate) and sulphate curves be adjusted according to the pressure at which the boiler is operated. In Fig. 10 are plotted the curves showing the relationship between carbonate and sulphate which must be maintained at various pressures to fix the intersection at such pressures. Thus, if a boiler is operating at 150 lbs. gage pressure, and the sulphate determination indicates 1,000 p.p.m., then the essential condition for prevention of formation of adherent scale is that the boiler water shall contain a little more than 90 p.p.m. of carbonate radical—a little more, because if only 90 p.p.m. is present, we are directly on the intersection of the curves, and either calcium sulphate or carbonate may be the solid phase; while with more than 90 p.p.m. the solid phase can be only calcium carbonate. If the gage pressure is 210 lbs., and sulphate 1,000 p.p.m., then the carbonate concentration must be slightly greater than 155 p.p.m.; but if sulphate is 750 p.p.m., the carbonate need be but slightly greater than 120 parts per million.

With a set of curves such as this, and the simple apparatus suggested for the determination of sulphate and carbonate concentration in the boiler house, the boiler water can be conditioned so that formation of adherent scale is inhibited. No analysis of the feed water is necessary or desirable, other than to test it for acidity now and then with bromphenol blue. The only chemicals required for conditioning are soda ash, if the boiler operates at or under 210 lbs., or sodium phosphate if the pressure is above that pressure.

Decomposition of Carbonate and Formation of Caustic.

It is more expensive to use sodium phosphate for conditioning than soda ash, but the rate of decomposition of carbonate is so rapid at the higher pressures that a sufficient amount can not be kept in the boiler to adjust properly the intersection of the calcium sulphate and carbonate curves. In Fig. 11 is shown the rate of decomposition of carbonate, when the gage pressure is 150 lbs. The experiment was performed in a small experimental boiler from which little steam was taken, and hence the rate of conversion was less than it would be in a boiler under actual operating conditions. Even so, at the end of 4 hours, 75 per cent of the sodium carbonate had become sodium hydroxide, and at the end of 6 hours, 91 per cent. The results obtained in actual boiler operation at different pressures, and with soda ash used for conditioning the water, are shown in Table 1. When it is remembered that 60 lbs. of CO_3 give only 34 lbs. of OH, the extent of the decomposition is readily realized.[7*]

[7*]The decomposition of sodium carbonate in boiler water is due to the very low partial pressure of carbon dioxide in the vapor phase in the boiler under operating conditions. Failure by Paul (Boiler Chemistry and Feed Water Supplies, J. H. Paul, pp. 137-138) to observe the relation of solubility of a gas to its partial pressure in the vapor phase has led him into intricate chemistry to explain the apparent anomalies.



The amount of Carbonate Radical necessary in Boiler Waters at various pressures and containing varying amounts of Sulphate Radical to inhibit adherent scale formation

FIG. 10.

It is not difficult to maintain sufficient carbonate for the proper adjustment when the boiler pressure is not much above 200 lbs. pressure; but the data on the boiler operating at 320 lbs. indicate how hopeless it is to attempt conditioning at this pressure with carbonate.

Caustic soda has its us, of course, in conditioning feed waters which are filtered before being sent to the

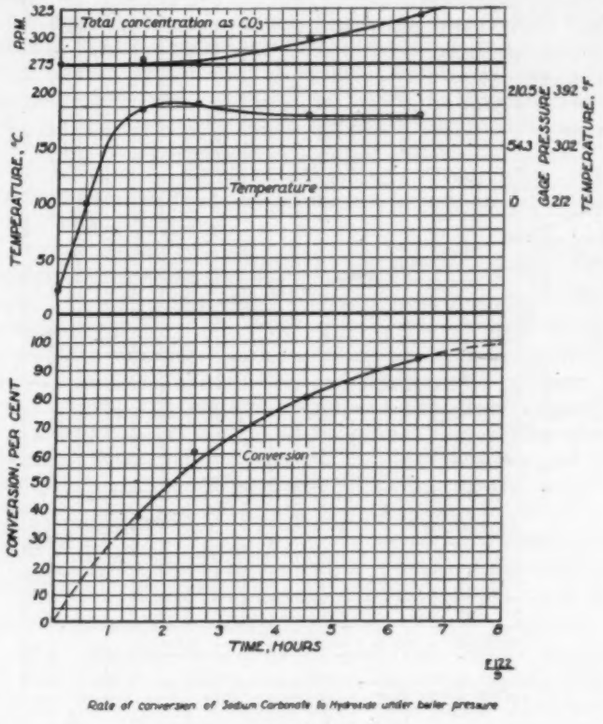


FIG. 11.

boiler, because it hastens the precipitation of the magnesium salts; but for internal treatment, its use is like carrying coal to Newcastle. Of course, it is hot surprising to find a large number of boiler compounds containing some caustic—that is a time-honored custom, even though a fallacy; but it is amazing that caustic should be used for internal treatment by anyone who has once followed the reactions in the boiler water.

The Relation of Excess Carbonate in Conditioned Feed Waters to the Solid Phase in Equilibrium with the Boiler Water.

When a feed water is treated with lime and soda ash in amounts equivalent chemically to the magnesium and calcium salts present, after complete reaction and perfect filtration there remain in solution such amounts of Mg^{++} and Ca^{++} as correspond to the saturation equilibrium of magnesium hydroxide and calcium carbonate, respectively. When such water is heated and evaporated, the magnesium hydroxide begins to precipitate immediately; the precipitation of calcium carbonate is delayed, because of its greater solubility at the higher temperature, until evaporation has increased its concentration to saturation. As the water evaporates, two changes are taking place which are altering completely the equilibrium conditions which existed in the beginning: In the first place, the sulphate concentration is increasing nearly in proportion to the evaporation; thus if the water contained 100 p.p.m. of sulphate at the start, when it has been concentrated three times its sulphate concentration has risen to approximately 300 p.p.m. Meanwhile, its carbonate concentration has not been increasing proportionately, because of the decomposition of carbonate and the accompanying formation of hydroxyl. Hence, while calcium carbonate was the solid phase in equilibrium at the start, the time comes when the increasing concentration of sulphate radical changes all this, and calcium sulphate becomes the stable solid phase.

Fig. 12 shows the results obtained in three specific instances, in which the water contains no magnesium salts, and hence may be treated cold with soda ash only. In *A*, an amount of soda ash equivalent to the calcium salts has been added; in *B* and *C*, such excess of soda ash has been added that the titration of the treated water with bromphenol blue shows an excess of carbonate equivalent to 21 p.p.m. of soda ash. Evaporation occurs at 150 lbs. pressure, and the decomposition of carbonate to hydroxide is assumed to be 50 per cent—certainly a fair figure in view of the data of Table 1.

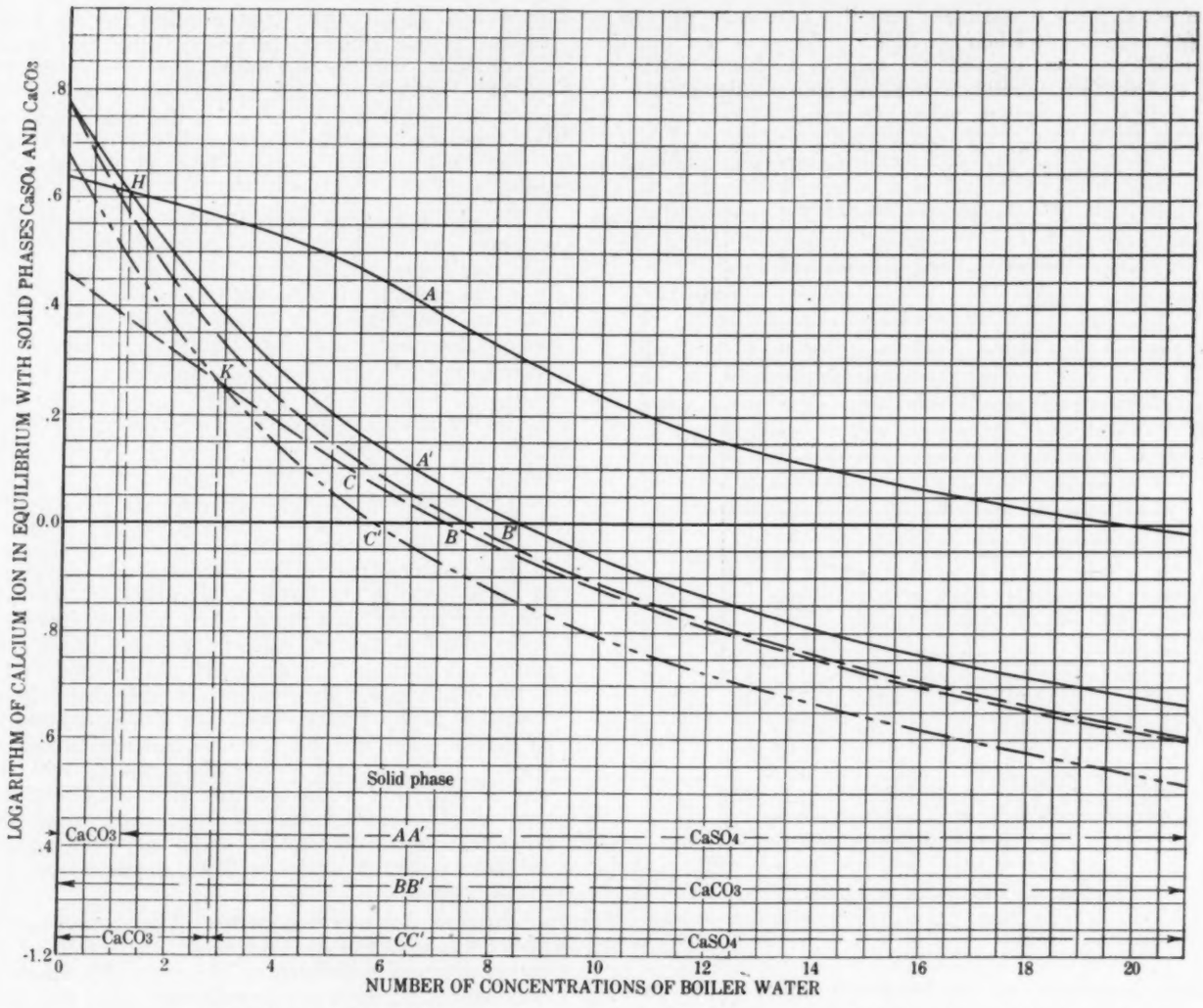
The vertical axis represents the calcium ion concentration, and the horizontal axis the number of times the original boiler water has been replaced by the inflow of feed water. Curve *A* represents the concentration of calcium ion in the boiler water necessary for calcium carbonate as the solid phase when no excess of carbonate is added to the feed water; and curve *A'* the concentration of calcium ion necessary for calcium sulphate as the solid phase. As previously stated, that solid phase which is in equilibrium with the lowest concentration of calcium ion will be the one existing in the boiler water. Hence in case *A*, calcium carbonate will precipitate as the boiler water is evaporated, until the intersection *H* of curves *A* and *A'* is reached, after slightly more than one concentration; from this point on calcium sulphate—adheren scale—will be deposited as evaporation continues.

In case *B*, in which excess of carbonate as stated above was added to the feed water, the results of evaporation are totally different. The curve *B'*, which represents the calcium ion concentration necessary for the appearance of calcium sulphate as the stable phase, never crosses curve *B*, the calcium ion concentration in equilibrium with solid calcium carbonate. Hence, calcium carbonate is the stable solid phase at all times, and no adherent scale will be deposited.

In case *B*, the feed water contained 110 p.p.m. of sulphate; in case *C*, all conditions are the same as for *B*, except that the water now contains 140 p.p.m. of sulphate. The results ensuing from evaporation are very different. The carbonate curve *C* is so nearly the same as carbonate curve *B*, that no separate plot has been made. The sulphate curve *C'*, however, is not at all the same as *B'*. It crosses the carbonate curve C at K, 2.8 concentrations. To the left of this point, calcium carbonate is the solid phase, and non-scale-forming conditions exist; to the right, calcium sulphate is the solid phase, and hence hard, adherent scale may form.

These examples serve to emphasize the fact that the conditioning of a water for boilers can not be based on the calcium concentration in the feed water, but must take cognizance of the sulphate concentration; and unless in each specific case the relation of sulphate in the feed water to the concentration it will attain in the boiler water is known, it is necessary to adjust the carbonate concentration in the boiler water according to the value found therin for the concentration of sulphate.

We have presented the principles governing the prevention of formation of hard adherent scale on the heating surfaces of a boiler, and the means of applying them,



Results of concentrating Monongahela River water containing 110 ppm of SO_4. (A) when treated with the theoretical amount of soda ash required, (B) when treated with an excess of 21 ppm of soda ash, (C) same amount of soda ash, but SO_4 concentration of water is 140 ppm. Gage pressure 150 lbs

F 122 27

FIG. 12.

TABLE I

COMPARISON OF CARBONATE TO HYDROXYL DEVELOPED IN BOILERS OPERATING AT DIFFERENT GAGE PRESSURES, WHEN SODA ASH IS USED FOR TREATMENT. (PARTS PER MILLION.)

Plant No. 1 Gage Pressure, 150 lbs. Boiler No. 2			Plant No. 2 Gage Pressure, 200 lbs. Boiler No. 8			Plant No. 3 Gage Pressure, 320 lbs. Boiler No. 1		
Date	CO_3	OH	Date	CO_3	OH	Date	CO_3	OH
11–25–23	180	13	1–10–24	156	41	12– 2–23	94	257
26	126	41	11	264	180	3	117	155
27	156	64	14	508	197	4	72	290
28	192	55	15	492	316	5	51	224
29	120	29	16	264	211	6	138	161
30	120	73	17	288	323	7	79	175
12– 4–23	160	45	18	324	211			
5	130	109		Boiler No. 9			Boiler No. 4	
6	156	166	1–10–24	168	68	12– 2–23	91	297
7	220	322	11	288	105	3	82	185
8	200	414	12	276	251	4	124	175
Mixed $NaHCO_3$ and Na_2CO_3			14	420	197	5	68	227
1– 2–24	200	112	15	312	245	6	140	206
3	166	112	16	216	217	7	98	235
4	158	78	17	432	217			

so we shall now turn to the question of disposal of the sludges formed by treating the water.

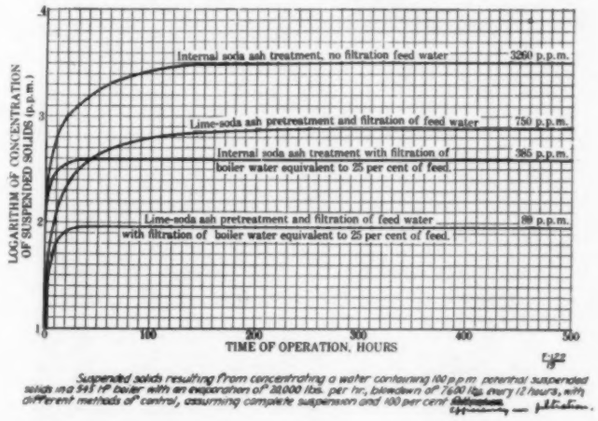
B. THE REMOVAL OF THE PRECIPITATED SLUDGE AND SUSPENDED INSOLUBLE MATTER

Whatever process other than distillation or freezing may be used in conditioning a water for boiler use, after theoretically perfect treatment, and although much solid material may have separated, the magnesium and calcium ion concentrations each correspond to saturation with respect to some solid phase. As evaporation and concentration take place in the boiler, precipitation of the solid phase occurs. The setting up of conditions to precipitate the solid phase which has the desired physical characteristics is purely a chemical problem while the disposal of such precipitated phases is just as definitely a mechanical problem.

Three courses are obviously open in dealing with the precipitated material resulting from treatment, as follows: (1) To disregard it completely, allowing it to accumulate in the boiler, and depend upon the blow-down to limit its amount; (2) to remove by filtration or settling the solids resulting from treatment outside the boiler, and disregard the further amount of solids precipitated in the boiler water during evaporation (the zeolite exchange process, while different, is equivalent to this); and (3) to filter continuously a portion of the boiler water whether it is the result of treatment (1) or (2), and thus be able to control it and the total amount of suspended material in the boiler water by varying the amount of water passed through the filter.

Specific Example of Disposal.

The conditions resulting in the boiler water from following these different methods may be illustrated by the following specific example: The water contains 100 p.p.m. of potential suspended solids; the evaporation is 20,000 lbs. per hour; the make-up water is 100 per cent; and blow-downs occur every 12 hours and


Internal soda ash treatment, no filtration feed water
3260 p.p.m.
Lime-soda ash pretreatment and filtration of feed water
750 p.p.m.
Internal soda ash treatment with filtration of boiler water equivalent to 25 per cent of feed.
385 p.p.m.
Lime-soda ash pretreatment and filtration of feed water with filtration of boiler water equivalent to 25 per cent of feed.
90 p.p.m.
LOGARITHM OF CONCENTRATION OF SUSPENDED SOLIDS (p.p.m.)
TIME OF OPERATION, HOURS
0
100
200
300
400
500

Suspended solids resulting from concentrating a water containing 100 p.p.m. potential suspended solids in a 545 HP boiler with an evaporation of 20,000 lbs. per hr., blowdown of 7,600 lbs. every 12 hours, with different methods of control, assuming complete suspension and 100 per cent [illegible]

FIG. 13.

amount to 7,600 lbs. each. (100 per cent efficiency in filtration and complete suspension of the precipitated material are assumed in all cases.) No allowance is made for moisture in the steam. The pretreatment with lime and soda ash is made by the cold process with ample time for precipitation, as separations are the most complete under these conditions owing to the increased solubility of calcium carbonate at higher temperatures.

With method (1) the amount of suspended material in the boiler water gradually increases with time of operation, until the maximum of 3,260 p.p.m. is reached. With method (2), the maximum is reached at 750 p.p.m. Method (3), with filtration of the boiler water equivalent to 25 per cent of the feed, reaches a maximum of 385 p.p.m. of suspended matter in the boiler water, when no outside filtration is employed; with its use, the maximum is reduced to 90 p.p.m. These results are shown in the curves of Fig. 13.

Filtration of the boiler water is equivalent, as regards suspended solids, to a continuous blow-down of like amount without its attendant loss of heat. The tremendous efficacy in maintaining a low concentration of suspended material with a relatively small amount of filtration is due to the fact that filtration is made at all times on water containing its maximum, and not its minimum, of material in suspension. The mathematical developments and formulas upon which the curves of Fig. 13 are based will not be discussed at this time, as they will be published in full later.

C. PREVENTION OF WET STEAM

The third phase of boiler water conditioning concerns the prevention of the boiler water being carried over in the steam, either in the form of minute droplets or as "slugs". Moisture in the steam is usually attributed to foaming and priming. We may define foaming as the result ensuing when conditions in the boiler water cause the walls of the bubbles formed to be stable as compared with those of pure water, and hence to break less readily. Priming we may consider to be the almost explosive transformation of the boiler water into steam, when by reason of load variation the pressure in the steam chamber is lessened. But even without either foaming or priming the rapid development and bursting of bubbles in the steam chamber is certain to result in the formation of minute droplets which are difficult to remove. While conditions of foaming are sometimes attributed altogether to sodium sulphate, sometimes to suspended matter, and at times to alkali and sodium carbonate and what not, we believe with Bancroft[8] that all of the materials in the boiler water, soluble and suspended exercise an influence. For a calorimeter test for moisture in the steam made shortly after the boiler is put on the line, and hence before its content of soluble and suspended solids has reached large proportions, will give distinctly different results from a test made when the boiler has reached its steady condition as regards solids.

Our evidence is to the effect that the amount of moisture in the steam steadily increases as the amount of suspended and soluble solids in the boiler water increases. We are confronted, therefore, with the following conditions: If we do not treat the water to prevent scale formation, the amount of soluble solids in the boiler water will remain low because these solids are removed in the form of adherent scale. On the other hand, if we treat the water to prevent the formation of adherent scale, the amount of soluble material in the boiler water is much higher and the amount of moisture in the steam increases in proportion to the amount of such soluble solids. The choice then seems to lie between having fairly dry steam and suffering the evils of adherent scale formation, or of obviating the latter, but incurring the troubles of the former, unless we can control wet steam satisfactorily. The dry pipe of a boiler answers the question of wet steam to a certain extent. The superheater will remove the moisture, but in so doing evaporates a certain amount of boiler water, and thereby

[8]Bancroft, W. D. Applied Colloid Chemistry, 1921, pp. 269-270.

either produces scale in the superheater corresponding to the soluble solids in the boiler water, or else carries these crystals in the steam to cause trouble further along in the system. One attempt to meet this condition has been the addition of socalled anti-foam compounds which may consist of certain organic chemicals which alter steam-water interface conditions. Such compounds, while their effect lasts, can change surface conditions so that excessive foaming is not apparent, but their sponsors to our knowledge have published no data showing definitely the amount of moisture still carried in the steam following their use. On the whole, this is a method which but temporizes with conditions at a high cost, and is not advisable for continuous practice.

Careful regulation of the hydroxyl content in the boiler water and the return to it of any cylinder oils, are the first steps in prevention of moisture in the steam. The final solution to the problem after such precautions are taken lies in applying to the boiler a mechanical purifier, which separates the denser boiler water from the gaseous phase steam. We believe, therefore, that the answer to the third phase of conditioning is mechanical apart from ordinary precautionary measures as suggested for protecting the boiler water.

PART II.

RESULTS OF BOILER WATER CONDITIONING IN PRACTICE.

The system of conditioning which we have been describing, employing carbonate as demanded by the sulphate concentration of the boiler water; controlling the suspended matter by means of continuously filtering a portion of the boiler water; and using a purifier of the centrifugal type in limiting the moisture in the steam, has

TABLE 2.- Evaporation, turbining, and tube loss records on boilers.

1921.

	Boiler No. 1		Boiler No. 2		Boiler No. 3		Boiler No. 4		Boiler No. 5		Boiler No. 6	
	Hrs. on	Steam, lbs.	Hrs. on	Steam, lbs.	Hrs. on	Steam, lbs.	Hrs. on	Steam, lbs.	Hrs. on	Steam, lbs.	Hrs. on	Steam, lbs.
Jan.			127.5	1219625	373.0	7023455	646.0	11786400	656.5	11019650	435.5	6600545
Feb.	180.0	2690390			486.5	7678320	473.0	9859325	486.5	9659125	218.5	3363940
Mar.					894.0	6816226	644.5	12316375	405.5	7240025	140.5	1613625
Apr.							254.0	4079750	598.0	12300400	297.0	4879575
May							540.0	8742825	318.0	5656950	88.0	1257980
June			Turbined		134.5	2339025	512.0	4000755	39.0	693225	161.5	2269300
July					81.0	853125	86.0	694250	299.0	3800550	49.0	405600
Aug.					116.0	1866150	184.0	2246050	345.0	5496075	103.0	1494675
Sept.					351.0	4913780	108.0	1755765	170.0	3512605	114.0	2111625
Oct.	Turbined		69.0	1145625	171.0	2756325	258.0	4516200	210.0	4316325	200.0	2097225
Nov.	399.0	5244525	718.0	10160475	Turbined		267.0	3258450	87.0	709800		
Dec.	228.0	3189225	545.0	7921875	471.0	7772700	Turbined		234.0	3159975	14.0	88725
Total	807.0	11024140	1459.5	20447600	2547.0	42019105	3719.5	64255135	3807.5	67564705	1821.0	25882695
Tubes renewed	5		29		30		31		34		20	

1922.

Jan.	333.0	5914350	501.0	7718100	654.0	10478325						
Feb.	482.0	7618160	382.0	5142150	114.0	1909050	396.0	6787465				
Mar.	369.0	4782260	117.0	1698700	387.0	4761060	629.0	8920155	Turbined		Turbined	
Apr.	48.0	501150	446.0	7127250	419.0	4876975	528.0	5875230				
May	Turbined		423.0	7184200	640.5	3989490	369.0	5934530				
June	382.0	4322150	Turbined 302.5	4890600	Turbined 295.0	1588525	430.0	7214025				
July	636.0	6258530	660.0	10620675			88.0	1283100				
Aug.	410.0	4501575	413.0	7034325	331.0	3568500	Turbined					
Sept.	158.0	1967550	268.0	5923125	190.0	1290993	334.0	5430721				
Oct.	482.0	7303200	560.0	9815500	96.0	1695525	94.0	1349400				
Nov.	336.0	4462395	713.0	7408475	240.0	3436775	328.0	5217675	95.0	1436100		
Dec.	Turbined 321.0	4570800	109.0	1327950	393.0	6241950	604.0	10073700	479.0	8026200		
Total	3947.0	52202120	4864.5	75881050	3759.5	43827148	3790.0		574.0	9461300		
Tubes renewed	41		67		31		30		3		0	

1923.

Jan.					552.0	6021600	192.0	2543775	744.0	9688150	744.0	10434450
Feb.			Turbined		192.0	2268825	411.0	6289725	550.0	8752575	660.0	9804600
Mar.	347.0	6014775	201.0	2398750	Turbined		505.0	8023275	344.0	4156375	609.0	10996925
Apr.	593.0	8278725	696.0	9963150	204.0	2350725	480.0	8151000	Turbined		Turbined 78.0	1484925
May	625.0	10018075	491.0	4683900	649.0	10125375					13.0	
June	294.0	4409925	516.0	8629725	472.0	7103860	Turbined				426.0	5775900
July	478.0	6951750	567.0	9675900	403.0	3797525			308.0	3611400		
Aug.	456.0	6831975	369.0	4148625	348.0	4058925	345.0	4849650	333.0	2529150		
Sept.	708.0	9024600	192.0	2225480	444.0	3535350	520.0	5412225	36.0	252720	12.0	
Oct.			20.0	304200	186.0	2145195	459.0	5693025	732.0	8547785	717.0	9524220
Nov.			Turbined 234.0	3339960	206.0	2880345	392.0	4880850	600.0	7316400	536.0	6613425
Dec.	Turbined		702.0	9929400			627.0	7005765	252.0	2132090	528.0	6109085
Total	3501.0	51529825	3988.0	51289035	3656.0	44287825	4031.0	52849290	3999.0	46898645	4322.0	60543530
Tubes renewed	42		36		53		18		20		20	

1924.

Jan.			688.0	10171200	321.0	4468425	552.0	7788302	358.0	4860375	526.0	6275075
Feb.	156.0	2338050	540.0	7459510	54.0	583050	696.0	9553050	612.0	8864675	84.0	896025
Mar.	600.0	8553675	388.0	5474625	Turbined		36.0	350025	552.0	6200025	148.0	1919775
Tubes renewed	3		1		13		5		1		1	

NOTE: The tube taken from No. 2 boiler was in good condition but was taken out and cut for a sample.

TABLE III—STEAM HOURS BETWEEN TURBINING AND STEAM LOSS

Period	Steam Hrs.	Steam, lbs.	Tube Renewals		Period	Steam Hrs.	Steam, lbs.	Tube Renewals	
	Boiler No. 1					Boiler No. 4			
Oct. 1921					Dec. 1921				
May 1922	1849	27,249,670	1921	5	Aug. 1922	2420	36,014,495	1921	31
May 1922					Aug. 1922				
Dec. 1922	2404	28,815,400	1922	41	June 1923	2948	47,079,271	1922	30
Dec. 1922					June 1923			1923	13
Dec. 1923	3822	56,100,625	1923	42	.....	3727	45,532,892	1924	5
Dec. 1923									
.....	756	10,891,725	1924	3					
	Boiler No. 2					Boiler No. 5			
June 1921					March 1922			1921	34
June 1922	3171	48,088,375	1921	29	April 1923	2312	31,960,400	1922	3
June 1922					April 1923				
Feb. 1923	3025	47,020,650	1922	67	.....	3783	44,314,620	1923	20
Feb. 1923								1924	1
Oct. 1923	3052	38,019,675	1923	36					
Oct. 1923									
.....	2542	36,374,695	1924	*1					
	Boiler No. 3					Boiler No. 6			
Nov. 1921					March 1922			1921	20
June 1922	2685	33,777,590	1921	30	April 1923	2013	31,235,975	1922	..
June 1922			1922	31	April 1923			1923	20
March 1923	2289	26,112,683	1923	53	.....	3067	38,398,430	1924	1
March 1923									
March 1924	3297	41,048,875	1924	13					

*The tube taken from No. 2 boiler was in good condition, but was taken out and cut for a sample.

been applied at the boiler plant of the Mesta Machine Company, beginning November 20, 1923. The second part of this paper is devoted to a consideration of the results obtained. We were fortunate in being able to make a direct comparison of the results of evaporating untreated and treated water from the same source. Boilers No. 2 and 3 are of the same type and rating, and operate under identical conditions. The system of conditioning was applied to No. 2, while no treatment whatever was given to No. 3,the practice at this plant for a number of years.

Fig. 14 is a drawing of the boiler and the de-concentrator which was used to remove the suspended material developed by treatment. Some details of the Heine boiler upon which the test was carried out are given below. The feed water was Monongahela River water filtered for city use. The chemical control of the boiler water was dependent entirely upon the use of the cabinet and the sulphate concentration apparatus, Fig. 2 and 3, respectively, during the last two months, and no analyses of the feed water were made during the entire test except for the purposes of a chemical balance. The history of the boilers at this plant from 1921 to the present time is given in Table 2. Table 3 is a summary of Table 2, and shows the steaming time between turbining, the amount of steam evaporated, and the tube renewals for each year.

DETAILS OF 545-HP. BOILER

Type of baffling	Horizontal, two passes for flue gases
Kind of furnace	Westinghouse stoker, 5 retorts
Grate surface, sq. ft.	76.87
Water heating surface, sq. ft.	5450.00
Superheating surface, sq. ft.	864.00
Total heating surface, sq. ft.	6314.00
Ratio of water heating surface to grate surface	70.9
Ratio of total heating surface to grate surface	82.1

Fig. 15 is a chart showing the concentration of carbonate which was maintained as demanded by the sulphate concentration. The hydroxyl content is that which developed from the decomposition of sodium carbonate added to the boiler water. The sulphate determinations in November and December were made by laboratory analytical methods, as the apparatus of Fig. 2 had not been developed at that time. They are being made daily with that apparatus at the present time, however, as a guide for the carbonate concentration which must be maintained.

Fig. 16 shows the condition of No. 3 and No. 2 boilers when opened March 23, 1924. In No. 3 boiler in which no treatment was used on the water, the heavy scale shown in *A* and *B* resulted after the evaporation of slightly more than 41 million lbs. of water. On C and D, taken from No. 2 boiler, only a slight film of carbonate scale was present, although 36.4 million lbs. of water had been evaporated. *A* and *B* are sections of a tube in the second row of tubes of boiler No. 3, *C* and *D* are from a tube in the first row of tubes of No. 2. The great difference is obvious, and it is attained by maintaining such a concentration of carbonate radical in the boiler water that calcium sulphate can not become the solid phase in equilibrium. Of greater practical import is the fact that while the sulphate scale is so hard that it requires periodical turbining, the film of carbonate scale does not grow, and may be readily washed out with high pressure water. As a matter of fact, the sections shown in the figure were never even washed out.

The characteristics of the boiler water, untreated and treated, are shown in columns 3 and 4 of Table 4. The things of note in these analyses are the differences in the untreated and treated boiler water as regards the calcium and magnesium content and the amount of total solids. In the untreated water the latter amount to only 481 p.p.m., while in the treated boiler water there are 4,470 p.p.m. This difference lies in the fact, as stated previously, that in the untreated water the calcium sulphate is being deposited as scale while in the treated water it is separating as calcium carbonate, leaving in the boiler water an equivalent concentration of soluble sodium sulphate.

The difference in scale and sludge from untreated water and from treated water is shown in columns 6 and 7, and 8 and 9, respectively. The scale from the untreated water is practically pure calcium sulphate. The sludge has very little calcium sulphate in it, but it is

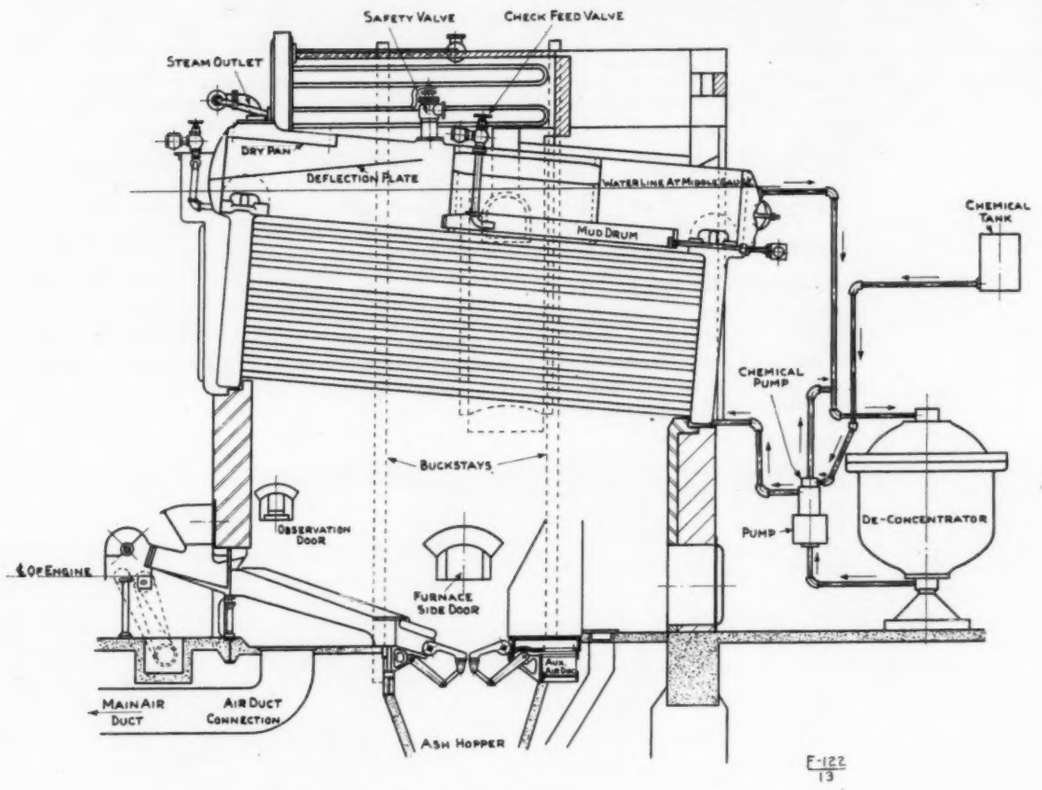


FIG. 14.—*Boiler and deconcentrator used in test.*

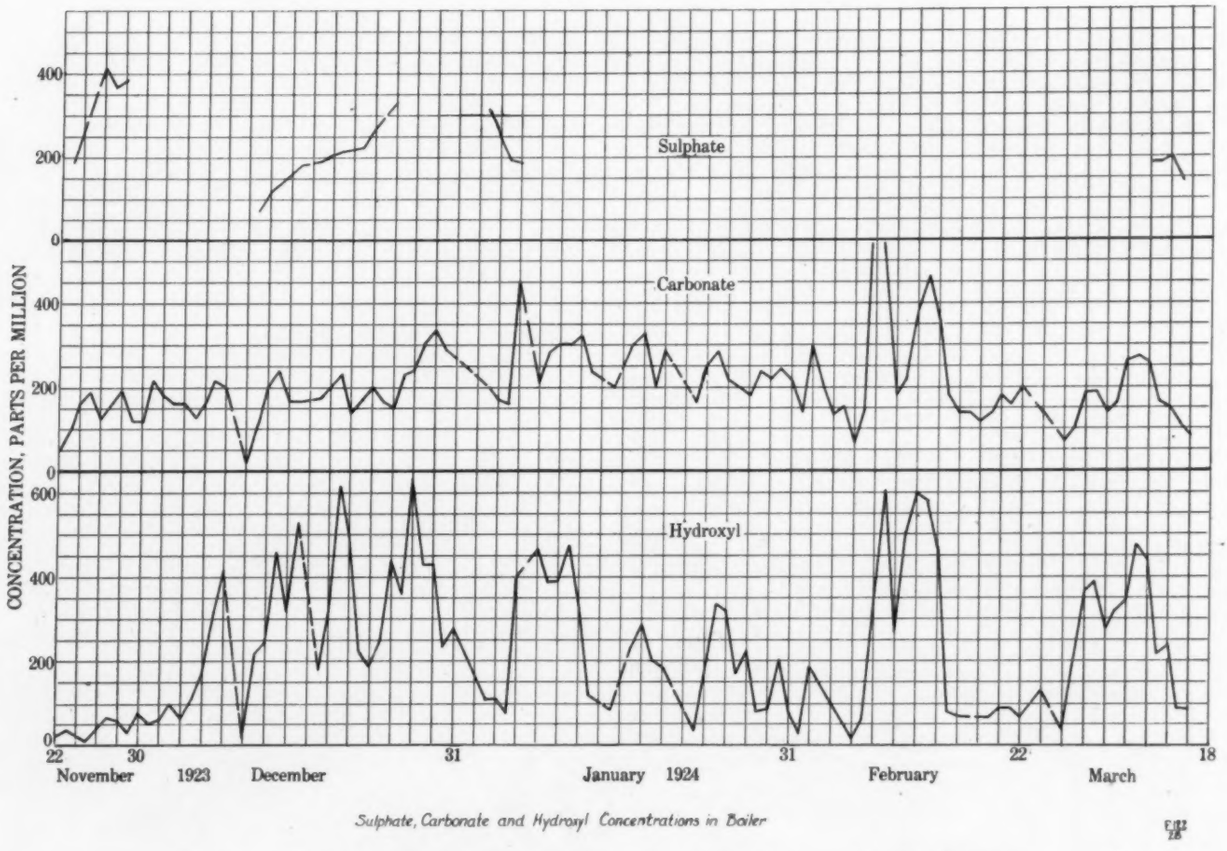


FIG. 15.—*Record of sulphate, carbonate and hydroxyl concentrations in boiler during test.*

TABLE IV

BOILER WATERS, SCALES, AND SLUDGES, DEVELOPED BY CONCENTRATING MONONGAHELA RIVER WATER, WITHOUT AND WITH CONDITIONING

Water (parts per million)				Scale and Sludge (per cent)				
				Constituents	From Untreated Boiler Water		From Treated Boiler Water	
Constituent	Untreated Feed	Untreated Boiler	Correctly Treated Boiler		Dense, Tightly Adherent Scale	Sludge	Eggshell Peeling Scale	Sludge
1	2	3	4	5	6	7	8	9
SiO_2	4.3	10.9	24.8	SiO_2	1.46	37.08	3.73	5.01
Fe	1.4	2.7	7.6	Fe_2O_3	2.15	15.87	6.97	3.80
Ca	32.3	31.8	2.3	CaO	36.57	1.36	44.79	38.47
Mg	5.0	21.9	0.5	MgO	1.63	19.95	5.10	7.79
Na	13.8	91.5	1742	SO_3	54.52	1.54	2.57	0.51
HCO_3	13.4	...	...	CO_2	....	....	35.53	30.22
CO_3	...	...	330	Loss at 105° C....	0.50	5.76	0.03	0.17
CH	...	2.7	395	Net ignition loss..	1.49	18.00	1.94	13.53
SO_4	110.4	273.9	1860					
Cl	7.3	43.2	108					
Total dissolved solids	181.2	481	4470					

high in iron and magnesium. In other words, we are separating most of the calcium sulphate from the untreated water in the form of hard, adherent scale. With treated water, the film and sludge are very similar in composition, both showing a high percentage of calcium carbonate. The first phase of conditioning—that is, the chemical—has therefore prevented the deposition of hard sulphate scale and has substituted for it a thin

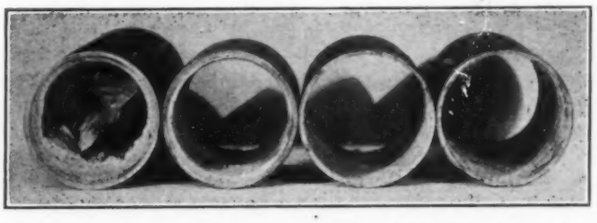


FIG. 16.—*Sections of tubes from No. 3 and No. 2 boilers. A and B, without treatment, from boiler No. 3; C and D, with treatment, from boiler No. 2.*

film of carbonate formation which *does not grow* as operation of the boiler continues, and which is so soft that it can be removed by washing when the boiler is opened. In fact, the condition of the boiler at the time of its last inspection (March 23, 1924) was better than the day it was put on the line, for in the water-legs, where the turbines were unable to get at the sulphate scale, the properly treated water is gradually softening such scale and removing it. After a few months more in service the boiler will be entirely free from sulphate scale.

In this test the mechanical phase of caring for the sludges precipitated was taken care of by the de-concentrator attached to the boiler. Through the filter was passing an amount of boiler water which was equivalent to 25 per cent of the feed water. Its ability to maintain a satisfactory minimum of suspended material in the boiler water is shown by the results of Table 5, covering a period of 16 successive days, in which time the maximum of suspended solids in the boiler water was 342 p.p.m.

During the period over which this test extended, to the present time, there has been absolutely no tube loss, no leakages have developed, and no trouble of any kind has been incurred.

TABLE V—SUSPENDED SOLIDS IN NO. 2 BOILER WATER DURING DECEMBER, 1923

Date of Month	Raw Water Entering, 1000 lbs.	Blow-down 1000 lbs.	Suspended Solids in Boiler Water, p.p.m.
4	345.4	5.6	122
5	378.3	3.3	101
6	375.2	4.0	127
7	357.4	3.9	154
8	266.9	3.8	109
9	3.0	2.0	...
10	285.6	4.3	228
11	230.1	5.5	124
12	348.0	5.8	342
13	360.6	8.6	...
14	290.2	6.1	168
15	365.5	5.0	264
16	319.1	6.0	...
17	414.9	3.4	158
18	468.2	6.2	204
19	257.3	4.8	65
20	377.9	4.5	57
21	279.9	4.5	115
22	309.3	2.5	274
23	249.3	5.0	...

The type of equipment used in the third phase of conditioning—that is, the control of moisture in the steam—has been a steam purifier working on the centrifugal principle. A diagram of the purifier is shown in Fig. 17. The steam enters at a point very near the top of the steam drum, so that siphoning with elevated water level is averted. In the present test the discharge pipe was in the steam space; connection should be made, however, outside of the drum in order not to be at the disadvantage of working against the pressure of the boiler.

In order to test the efficacy of such a purifier, throttling calorimeters were placed one on the steam outlet of one of the drums of boiler No. 2 not equipped with a purifier, and the other on the steam outlet of the other drum equipped with a purifier. Differential thermocouples attached to the two calorimeters were connected to a two-point Leeds and Northrup recording potentiometer. Fig. 18 shows the type of record obtained. The

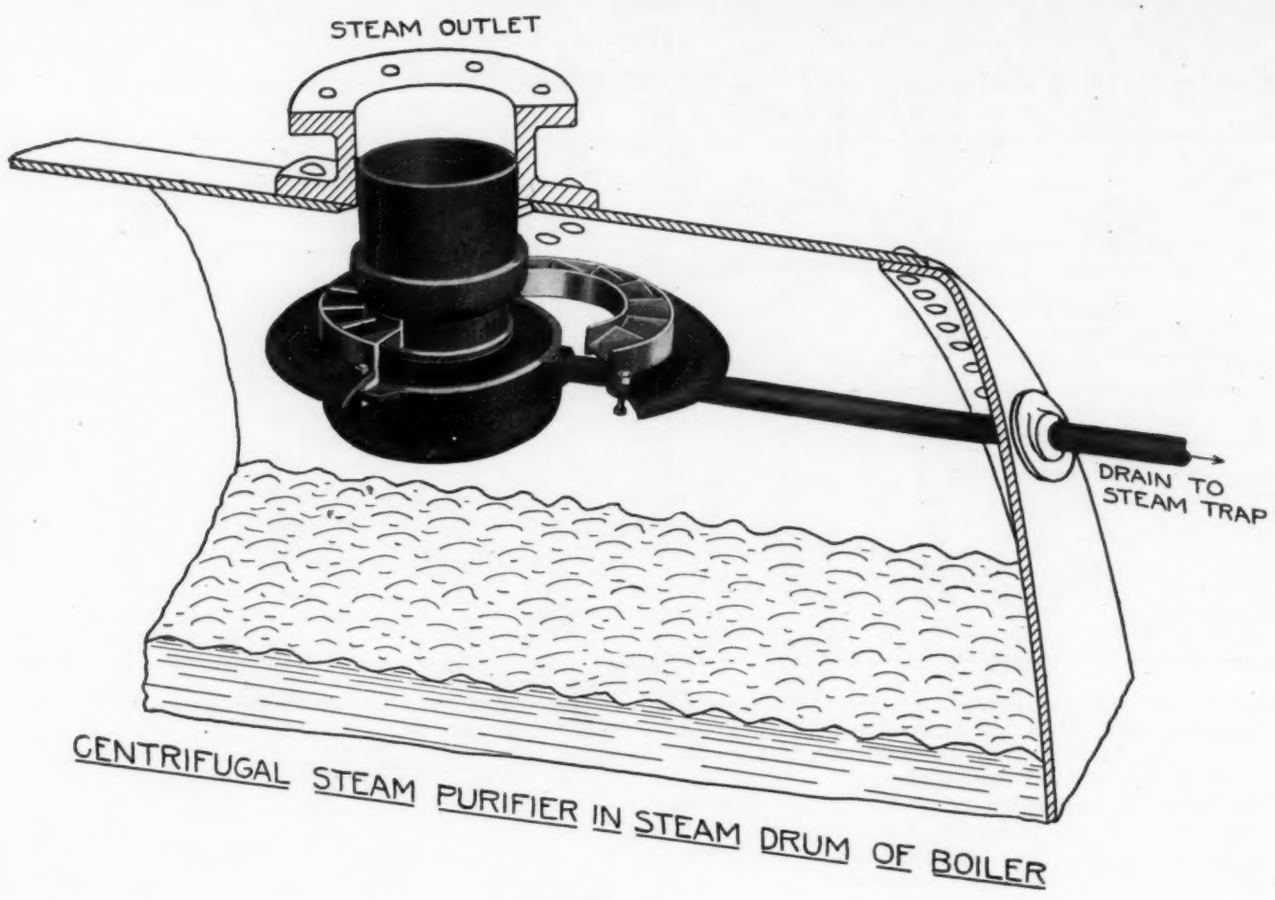
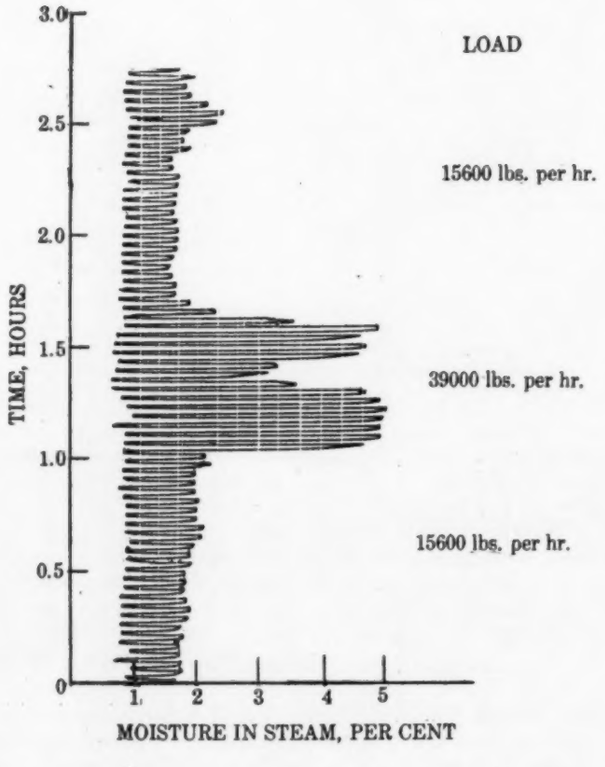


FIG. 17.



Moisture in steam with and without steam purifier

FIG. 18.

points to the left on the diagram are those corresponding to the differential thermocouple in the calorimeter in conjunction with the steam purifier, and show that the steam delivered through it contained not more than 1 per cent moisture, no matter what was the load on the boiler. Without the purifier, when the load was low, the amount of moisture in the steam averaged from 1½ to 2 per cent when the boiler was operating at low rating; but when it was carrying a heavy load, the amount of moisture rose immediately to 5 per cent, or perhaps more, as the limit of the calorimeter to record moisture was approximately 5 per cent. It should be noted that the velocity of steam flow through the purifier was relatively slow, and that it was most efficient when the velocity was increased.*

In an efficiency test on this boiler made some time previous to our work the amount of moisture in the steam was found to be 1 per cent. The boiler water was untreated, and hence contained only a small amount of soluble solids and suspended matter, any precipitated material being deposited as adherent scale. When the water was fully treated, the amount of suspended and soluble matter had materially increased, and likewise the amount of moisture in the steam had increased. The tests which we have made show that simple equipment of the type shown, even with the connections into the boiler itself, will maintain the moisture at a low content, even though the rating changes rapidly; but without such equipment

*Subsequent determination made of the "normal" reading of the calorimeters used showed a zero correction of 0.4 per cent, so that the figures given in the text are all high by approximately that amount. Also, the installation of a smaller purifier, designed to give the proper range of steam velocities reduced the moisture to zero within the accuracy of the determinations.

the amount of moisture rises to proportions which are entirely unsatisfactory.

Data on this type of steam purifier obtained at another plant, with the connection to the outside of the boiler show the amount of moisture under severe conditions to be low. What can be done by a purifier working on the principle of wiping out the moisture has been discussed by Kuhman[9].

[9]Kuhman, Louis F., Dirty steam no longer necessary. The Blast Furnace and Steel Plant, June, 1923.

SUMMARY

1. There are three phases to boiler water conditioning—namely, (a) the prevention of scale formation by making the solid material precipitating therefrom calcium carbonate, and preventing any deposition of calcium sulphate. This phase is chemical, (b) the separation of the precipitated sludges. This phase is mechanical. (c) the separation of moisture from the steam. This phase is mechanical.

2. Apparatus suitable for boiler-room use has been described, which enables the boiler operator to determine easily the necessary sulphate and carbonate concentrations in his boiler water. It has been pointed out that analyses of the feed water are needless, unless acidity may be encountered in the water.

3. The mechanism of scale formation has been indicated. Whether materials form adherent scales or sludges is determined by their change of solubility with temperature change.

4. The carbonate concentrations which are necessary in the boiler water to inhibit the deposition of hard adherent scale when the sulphate concentration varies have been presented in a series of curves suitable for boiler room use.

5. The rapid development of caustic soda from soda ash at boiler temperatures has been discussed, and the error in using caustic soda as treatment is pointed out.

6. The possibilities of error if the control of conditioning is attempted on the feed water have been emphasized.

7. A specific example has been discussed relative to the merits of different methods of sludge removal.

8. The causes of wet steam have been discussed, and methods recommended for its control.

9. The results of applying the principles herein advanced in plant operation have been presented.

The Chapman-Stein Recuperator

By WILLIAM C. BUELL, JR.*

THE regeneration or recuperation of air in high heat processes has been employed for a hundred years or more, but the early designers were not actuated by fuel cost reduction but by the fact that the use of preheated air gave the higher furnace gas temperature which is essential in the working of raw materials. It is only by the addition of sensible heat in the air that the reduction of iron ore, the making and refining of steel, the making of glass and similar processes are commercially possible.

While the increase in flame temperature is the first consideration in such processes, the contingent fuel saving from the sensible heat salvaged from the waste gases and returned in the air brings about a very great reduction in fuel quantities, and in later years improvements in regenerative and recuperative devices have been premised upon the value in dollars and cents of the heat which may be salvaged.

The earliest method of salvaging waste heat was with cast iron recuperative elements, and, in spite of much mechanical and leakage trouble, these were used until the late sixties, for up to the time the Seimens Brothers built their first regenerator on the crucible melting furnace, the cast iron recuperator was the only method available.

The history of modern steel making really dates from the employment of the first regenerator.

Since the first regenerator was used, experience and research have greatly aided in its development, but it has long been recognized that regenerators were far from perfect heat salvaging devices, and many investigators have been working on the recuperative installation which, today, is coming into more general use due to a better understanding among the operators of the advantages that accrue through the use of the recuperator as compared with the regenerator and the knowledge that through much research and experimentation, the recuperator is capable of producing a better economic operation than the regenerator.

Today there are a number of recuperative devices on the market, several of them worthy of consideration, but the tile recuperator invented by Charles M. Stein and patented by him in 1902, and since improved, has secured a larger application both here and abroad than any other style or type, due to the fact that, owing to the basic features of its design, it has eliminated to a great degree the two major causes of recuperative troubles—namely, leakage and breakage.

This paper deals with the principles of design and operation of the Chapman-Stein recuperator and includes a description of a number of installations which are now in successful use in this country.

Basic Principles.

Although an elementary subject, it will probably be in order to review briefly the basic factors affecting and comparing regenerator and recuperator design and action.

The regenerator is alternately a heat storage and heat supplying device, the waste gases heating the checkers and, after the reversal, the checkers heating the air.

The recuperator is a heat transfer device, the heat from the waste gases flowing continuously to the cooler air through the transfer medium. Thus the use of recuperators eliminates the manual operation of reversing and, as the recuperator works under a more nearly constant temperature condition, brick spawling and disintegration are entirely absent.

With regenerators the temperature of the heated air varies during the period of reversal, through several hundred degrees, and consequently furnace temperature is fluctuating through nearly the same range

*Engineer, The Chapman-Stein Furnace Company, Mt. Vernon, Ohio.

unless manual adjustment is constantly made. With the recuperator, the air temperature is constant, or nearly so, and consequently furnace temperatures are likewise. In certain processes in the manufacture of glass, temperature conditions once established are

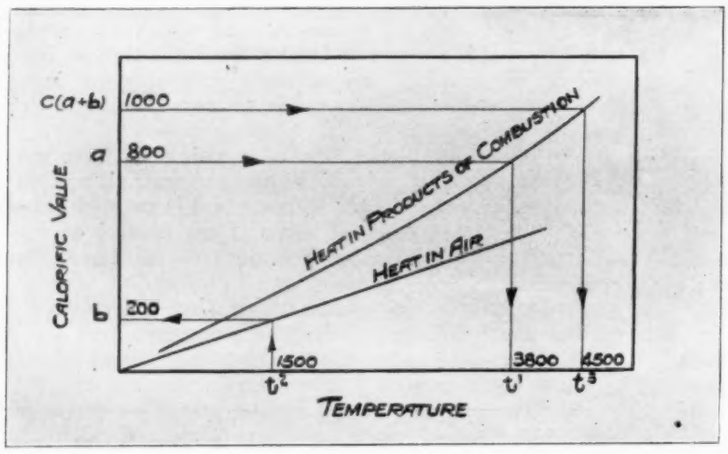


FIG. 1.

maintained constant, without manual attention, over a period of days and often weeks.

As previously stated, the primary object of preheat was to increase flame temperature. Reference to Fig. 1 will show how this was accomplished. The curve (Heat in Products) represents the sensible heat at any temperature in the gases from the perfect combustion of a unit of fuel. The line (Heat in Air) shows the sensible heat at any temperature in the air

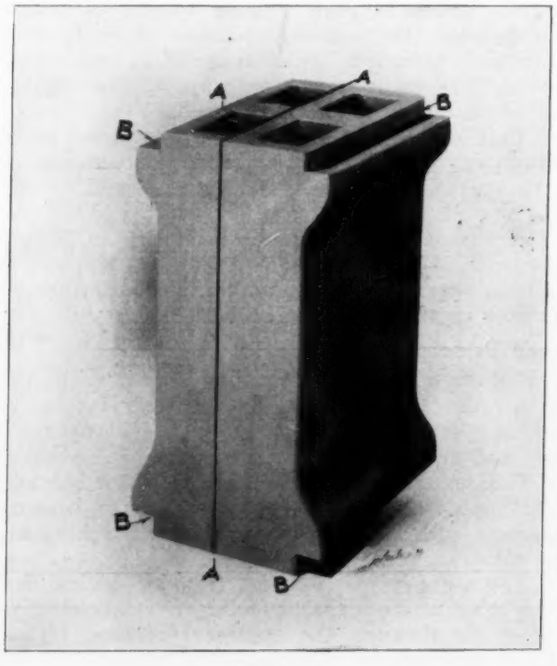


FIG. 2.

necessary to bring about the perfect combustible mixture of one unit of fuel. Thus, if from point "A," representing the calorific content of one unit of fuel, a line is drawn horizontally to curve (Heat in Products) and vertically downward as indicated, t^1 will indicate the theoretical flame temperature with cold fuel—cold air.

If it is found or assumed that air is preheated by recuperation or regeneration to temperature t^2, then, by following vertically upwards to line (Heat in Air) and thence horizontally to the left, the value "B" will represent the sensible heat in the air at the indicated temperature required to burn one unit of fuel. If the sum of the values "A" (known) and "B" (found) is taken, we now have a new and total calorific value of the fuel. If the proceeding first described is duplicated, starting at value "C," the total flame temperature t^3 is found.

From the foregoing calculation the per cent direct fuel saving may be found by calculating, $\frac{b}{a} = y\%$, and the increase in flame temperature by

$$\frac{t^3}{t^1} - 1.00 = z\%$$

Further, in standard practice, the toal saving indicated by the sum of y plus z is easily accomplished.

In recuperator design considerable thought and study must be given to the proper size of the device. It is possible to approach 100 per cent recuperator efficiency, although it is plain that this saving would not be economically warranted on account of the large structure which would be required. With fumeé (waste gases) at 2000 deg. F. or above, 40 per cent to

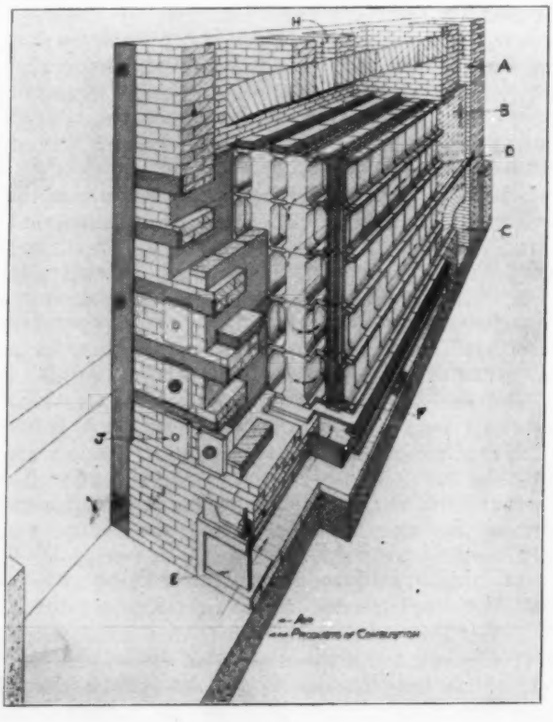


FIG. 3.

60 per cent recuperative efficiency, representing a total saving of 18 per cent to 28 per cent of the fuel, may be economically accomplished, and with fumeé temperatures, 1000 deg. to 2000 deg. F., designs should be premised on a 20 per cent to 30 per cent

recuperative efficiency which would affect a saving of approximately 8 per cent to 20 per cent.

Recuperator Design of Charles M. Stein.

The recuperative design of Stein is based on the employment of a quantity of special tile blocks, the basic design of which is shown in Fig. 2. These blocks are made as indicated and in halves, being separated on the lines AAA as drawn. Blocks are placed with the four air passages in the vertical plane and the fumeé passages in the horizontal plane. The blocks butt end to end to give the proper length and are spaced sideways from each other by means of spacer tile which are placed in mortise "B." The method by which the recuperator is built is perhaps better explained by reference to Fig. 3. The fumeé enters the recuperator through flue "A," enters chamber "B" at end of recuperator and then flows horizontally through the tile as indicated to the opposite end, where it turns through 180 deg. and enters stack flue "C" through the second pass. The baffle wall "D" prevents the short circuiting of the flow from "B" to "C." It is obvious that recuperators can be made to embody any number of passes, or of any height or width. The air enters the recuperator through damper "E," flowing under the body of the tile into the air ducts "F" and passes upwards to collecting chamber "C" and from thence into the air supply flue "H."

In addition to being based on a unit design, the recuperator action violates none of the physical laws of the flow of gases, and in this feature it is unique and stands alone. The fumeé entering the recuperator at the top and rapidly cooling and becoming heavier, seeks lower levels until it enters stack, where it is carried upward by the usual stack action.

Cold air entering channel at "F" and heating and losing weight, flows upward by gravity action to collecting chamber "G" (Fig. 4), in which is frequently found a static pressure in excess of 0.25 inches of water.

In the Stein design, forced draft is unnecessary on account of the condition above mentioned, for, with proper design of recuperator, air flues and burner ports are always under pressure greater than the atmosphere, and with proper manipulation of stack damper, the pressure condition within the furnace chamber may be as desired by the heater.

As forced draft is not used, the extreme difference of pressure between fumeé and air is so very small,

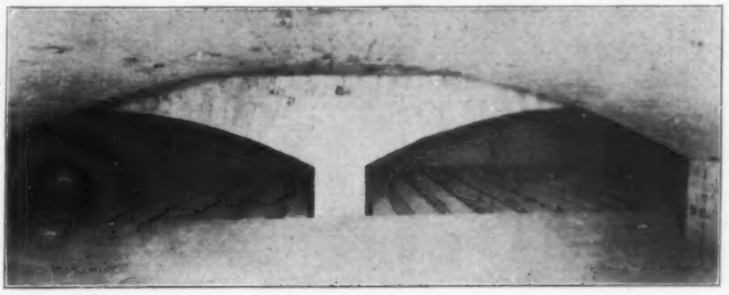


FIG. 4.

that to all intents and purposes, pressure conditions are perfectly balanced within the recuperator. This is the secret of the success of the Chapman-Stein recuperator, for without pressure differential there will be no leakage.

Again, with the Stein design, the tile recuperator elements may expand and by weight alone settle to their original position upon cooling, for the recuperator is entirely free at the point where the top forms the bottom of the collecting chamber "G." This does away with leakage through expansion cracks and the distortion which is inherent in other types.

Again, the design permits large transfer areas for a block having a total over-all volume of 0.45 cu. ft., has 150 sq. in. of surface available for transfer on both the fumeé and air surfaces.

If dirty fuels (raw producer gas or pulverized coal) are used for fuel, or if large quantities of dust from the process are carried in the fumeé, the flues may be cleaned with the furnace in operation through the holes which are normally closed by the plugs "J." There is a hole registering with each fumeé pass.

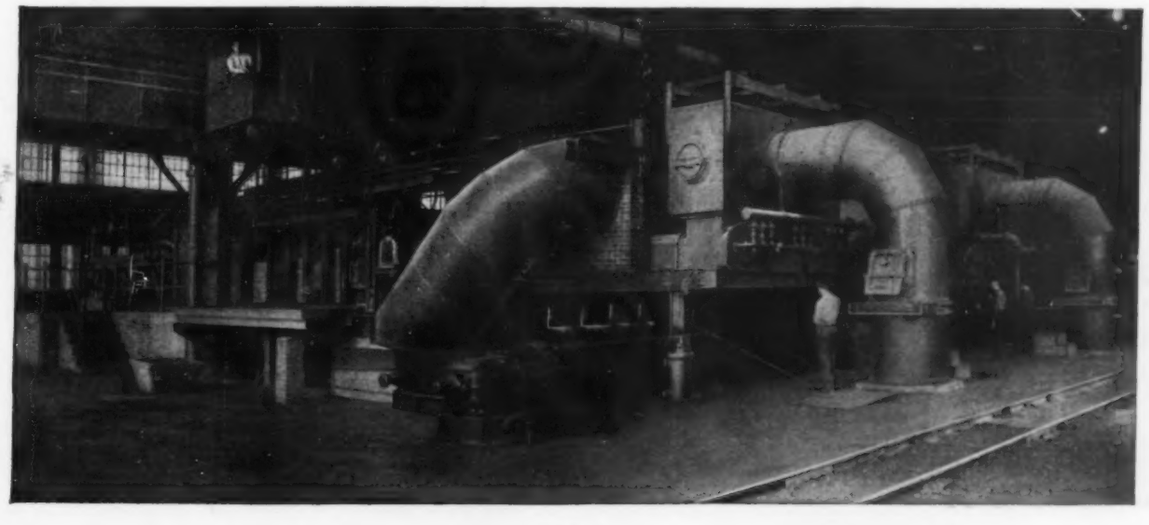


FIG. 5.

Experience has shown that with raw producer gas carrying considerable dust, an annual cleaning of the flues is all that is necessary to maintain heat transfer surfaces in good condition.

Furnace Operation.

The operation of the furnace is very simple. As explained before, hot air collects under pressure in

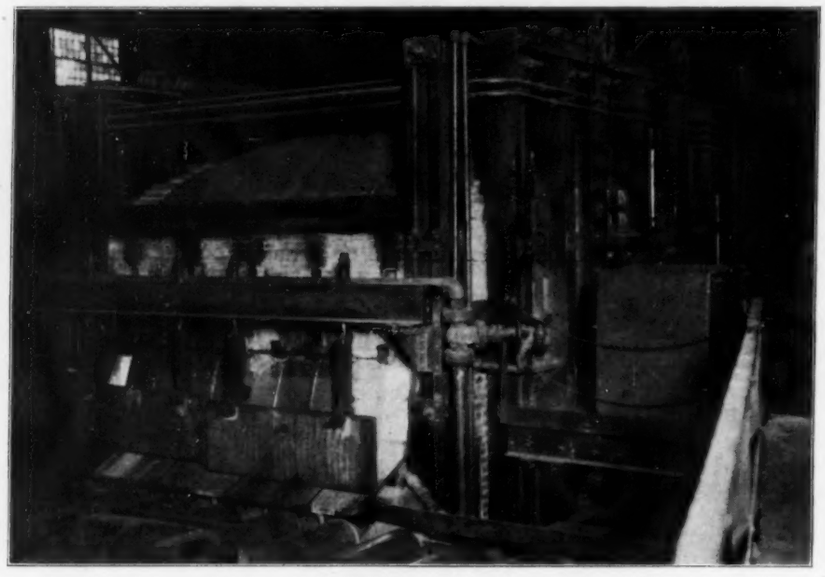


FIG. 6

collecting chamber "G" and enters burner ports by means of flue "H" (Fig. 3). The air for furnace operation is controlled from damper "E" which is operated from any convenient point. Of course, fuel supply is adjusted in the usual way. The furnace pressure and waste gas removal are controlled entirely by the stack damper, which is arranged to operate at a point adjacent to the air control, and no further control of conditions is necessary.

On a square foot basis the transfer of heat per degree differential of temperature appears to be much greater than any of the values at present ascribed. At the minute, we have not accurate data on this value, but experiments are being conducted and we hope to be able to announce the figures in the near future.

Such figures as we have available indicate a transfer in excess of 2 Btu. per square foot per degree differential per hour when fumeé enters the recuperator at temperatures higher than 1900 deg. F., and in several cases transfers in excess of 3 Btu. have been shown.

Economies of the Chapman-Stein Recuperator.

When applied to a simple furnace a great overall fuel economy is always accomplished and an equal betterment in furnace operation is secured that frequently makes the over-all saving of furnace operation double the fuel saving. The same general statement holds good where the recuperator replaces regenerators, but to a lesser degree. We have figures available showing where natural gas consumption was cut in a regenerative furnace from 180,000 cu. ft. per day to 110,000 cu. ft. after recuperator was installed, and in another case, from 90,000 cu. ft. per day with regenerative type to 50,000 cu. ft. per day after recuperator was installed. These figures quite likely will be taken as extreme, but in the latter case cited, the plant in which the installation was made is credited with having very fine fuel and furnace practice.

It should be noted at this point that the heater must be shown and made to understand that the basic principles of regeneration and recuperation are different. As an example of a situation in which the details of operation were not carefully explained to the heater, we can cite the case of a regenerative furnace to which we applied recuperators. For a long period of time the furnace in question had been consuming about 525 gallons of fuel oil per day after the recuperator was installed, and an exciting telegram informed us that for over a week the furnace had consumed 550 gallons gallons per day, or 25 gallons per day more than with the regenerative type. Our representative, upon arrival, took control of the furnace and operated it with a consumption of 340 gallons per day, and the consumption has been approximately at this figure since. The explanation of this situation lay in the fact that the heater was not satisfied with his furnace operation unless the recuperator showed heat color the

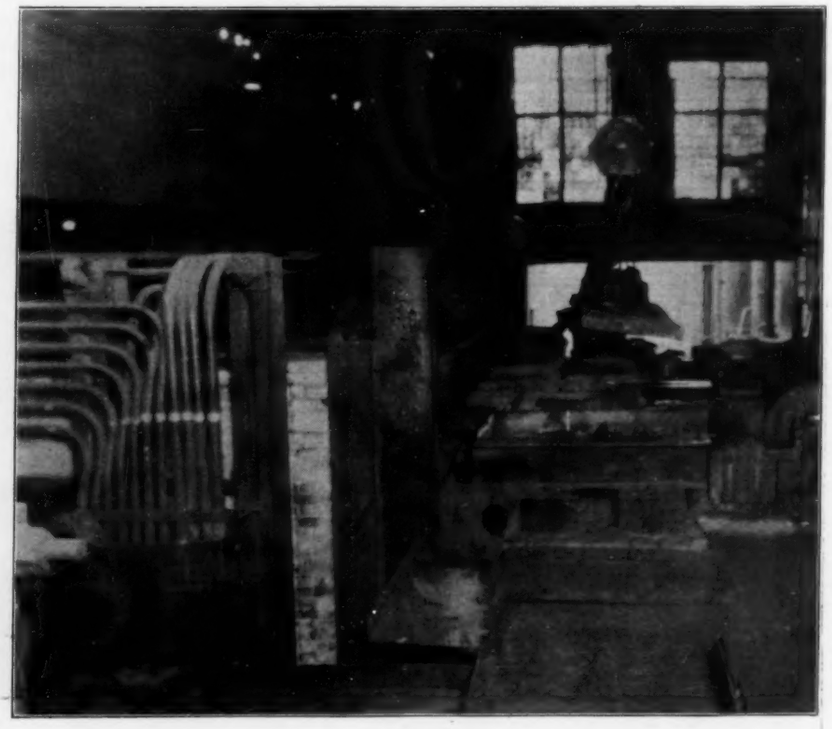


FIG. 7.

same as his checkers. Frequently, except in the first pass or two of the recuperator, no heat color will be observed.

In every installation we have made fuel savings have been in excess of 20 per cent, and improvement of furnace conditions in general has brought about a contingent savings of moment.

Installations.

In a little over three years, and working against the normal American prejudice against any device of European origin used in productive practice, and in the face of post-war slump, we have made some 60 recuperator installations, all of which designed and installed by the licensees are still in daily use and none of which to this date have been repaired, or so far as we know, required repairs. We have standard recuperators working which are receiving fumeé at temperatures as high as 2500 deg. F., and delivering the air at temperatures in excess of 2000 deg. F., and it is believed that with the refractory material as used, the Chapman-Stein recuperator is capable of receiving fumeé at temperatures as high as 3000 deg. F., operating indefinitely at this temperature.

Of the three installations which will be described, the first has been in use over two years and been subject to at least 100 cold shut-downs, and the users state that they cannot see that the recuperator is changed in any regard. In fact, the output has increased. The installation of two furnaces, Fig. 5, is at the Youngstown Sheet & Tube Company on a 14-inch skelp mill. These furnaces are each 11 ft. in width and about 28 ft. heating length. They were designed to deliver 12 tons of slabs per hour each, and to replace three furnaces of the continuous regenerative type. At the normal production of 12 tons per hour each, they are credited with having produced this tonnage of slabs on a consumption of about 169 lbs. of coal in the producer per ton of metal heated. However, as a greater tonnage of skelp could be rolled, the furnaces for 18 months have been delivering 20 tons per hour each and coal consumption has jumped to about 220 lbs.

Due to the fact that, owing to the greater volume of gases handled, velocities have increased materially and the recuperator has been unable to return the percentage of heat of which it is capable at the lower rate. This is shown in air temperatures which, at the smaller capacities, was 1450 deg. F., and at the higher capacities is only 1150 deg. F. That these furnaces have been able to deliver this large tonnage at the relative low fuel figure has been due to the fact that it is possible to run the furnaces hot throughout their length and salvage the considerable amount of heat entering the down-takes to the recuperators and return a large proportion of this in the heated air.

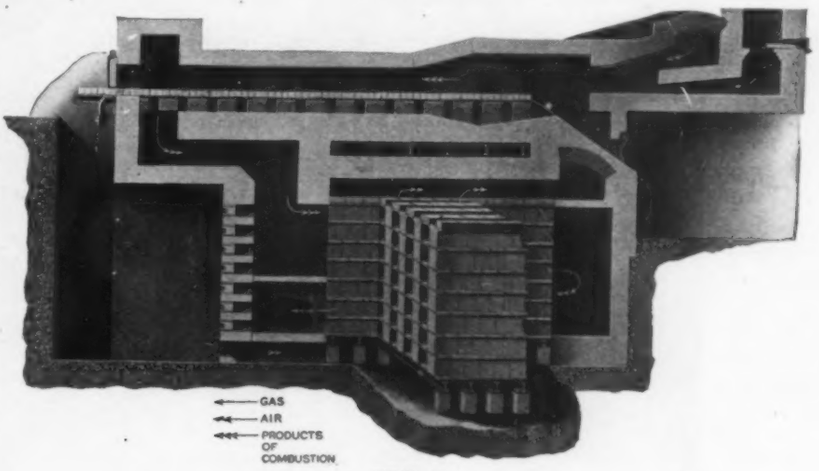


FIG. 8.

Fig. 6 shows the discharge end of one of two continuous slab-heating furnaces serving a 42-inch universal mill in the same plant. These furnaces have been in operation about six months, but we have not as yet received figures on tonnage or fuel consumption other than the oral statement that the results secured are satisfactory. These furnaces are approximately the same size as the furnaces described above, but gas and air flues enter from the bottom rather than from the upper front as in the first installation. Fig. 7 gives the method of and arrangement for charging slabs. In connection with the furnace just described it is interesting to note that fuel and air enter the furnace under the skid pipes. There has been considerable discussion among furnace designers as to the correctness of this method of firing, and considerable has been written lately with the majority opinion against the method, but results in this particular installation have been so satisfactory that we are fully convinced this method of firing is basically sound, when the mixing of the air and fuel takes place at the low velocities which are an inherent feature of the Chapman-Stein recuperator.

Fig. 8 gives quite an accurate diagram of the top fired end discharge furnace serving No. 2 mill at Youngstown. (Fig. 5.)

Fig. 9 is of a continuous furnace, but with side discharge. In conjunction with the incorporation of side or end discharge in mill practice, it is interesting to note that with a side discharge furnace the fuel consumption is approximately 15 per cent under the end discharge furnace, other specifications being the same.

Fig. 10 shows a group of furnaces recently put into operation at the plant of the

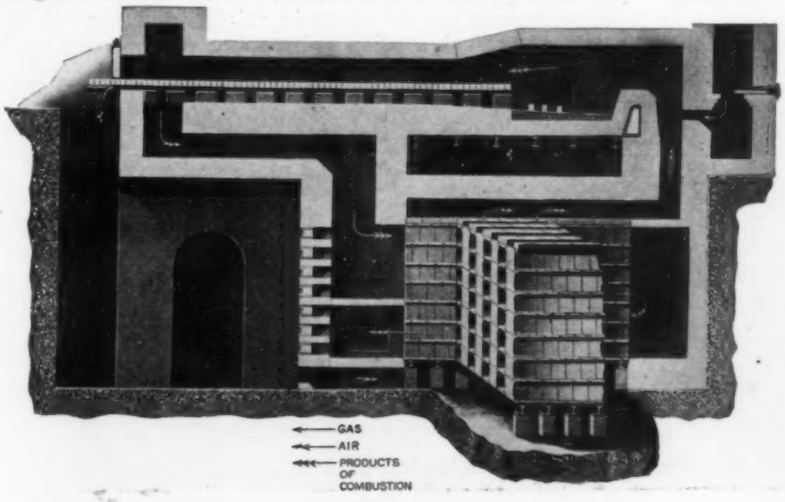


FIG. 9.

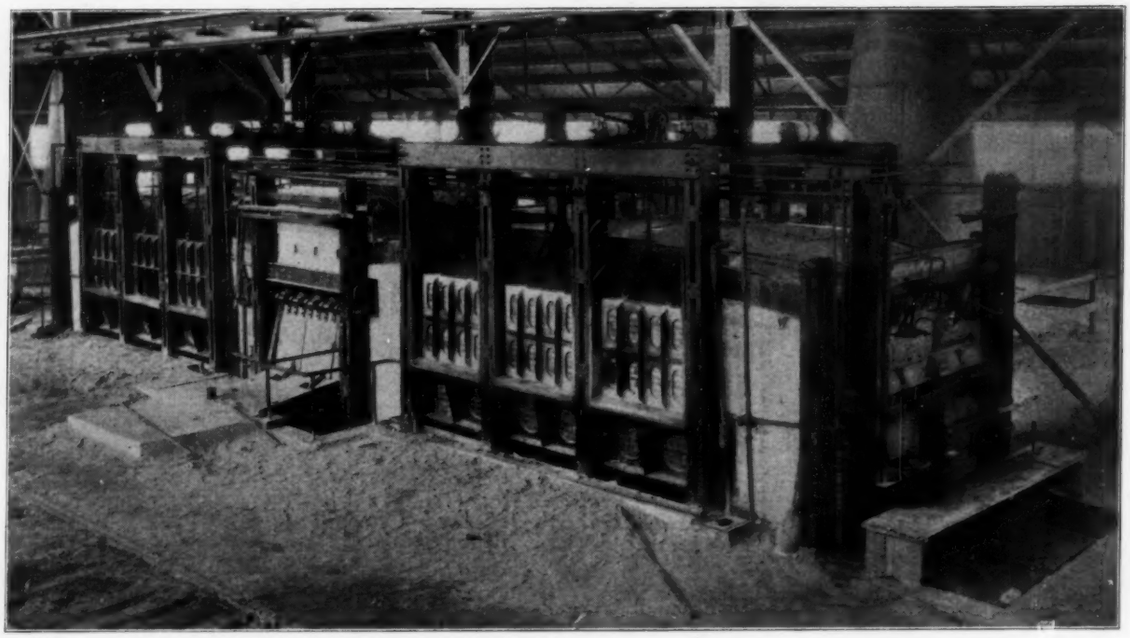


FIG. 10.

American Puddled Iron Company, Warren, Ohio. This group consists of a continuous furnace (in the center) which has a hearth width of 6 ft. and a length of 27 ft. The furnaces at either side are of the open hearth or sand bottom type (7 ft. wide, 15 ft. long), but do not reverse as they are fired only from the far end. This installation is for heating wrought iron ingots, each weighing a trifle over one ton, and the continuous furnace is to preheat these ingots to a temperature of approximately 1900 deg. F. By means of a manipulator an ingot discharged from the continuous furnaces is placed in an open hearth furnace and heated to the final temperature of approximately 2500 deg. F. for rolling. This group of furnaces is serving a 36-inch continuous mill rolling skelp and other flats from 15-inch square ingots. A front view of the same installation is shown in Fig. 11.

This installation has been completed about 10 months, but it has been in operation only a few weeks and accurate figures are not available, but it has been stated at the plant that operation both as to temperature secured and fuel consumption have been entirely satisfactory.

We have recently completed at the plant of the American Steel & Wire Company, Worcester, Mass., a continuous furnace having a heating chamber 5 ft. in width and with a 28-ft. effective heating length. This furnace is designed to deliver 7 tons billets per hour properly heated for rolling, with a guaranteed consumption of 12 gallons fuel oil per ton of metal heated. This furnace has just been placed in operation and no figures are available.

Only mill type furnaces have been described and it should not be taken from this that the Chapman-Stein recuperator is limited in furnaces of this type. We have made installations to many types of continuous and periodic furnaces in the steel and other basic industries and we do not believe that there is a heating operation carried on with temperatures above 1000 deg. F. of any sort to which we cannot successfully and economically apply this device. We believe we have one of the largest fields in connection with soaking pits and from investigations of this subject that we have made, believe we can effect material fuel saving and a large additional operating economy.

We are pioneering in many directions in several industries, and while several of the applications and installations we have made might logically be considered radical, we can point to an engineering record unblemished by a single failure.

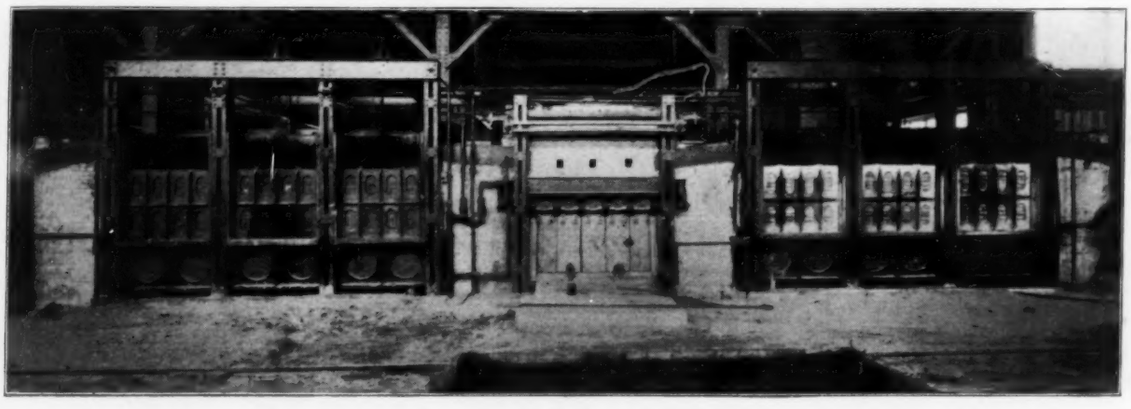


FIG. 11.

DISCUSSION

A. E. Miller: What is the maintenance cost with the coal type?

A. L. Milton: I would like to ask, regarding the fuel consumption, if the figures Mr. Buell gave, viz., 180 to 220 lbs. of coal per ton, covered an operating period of say a month or so, including the heating up of furnace over Saturday and Sunday, ordinary mill delays, etc. I should also like to ask the following question: The statement was made that recuperative furnaces had replaced regenerative furnaces. What is the saving in lbs. of coal per ton of the recuperative furnace over the regenerative furnace?

W. Flanagan: I would like to ask Mr. Buell what he considers the economical length in the average continuous billet heating furnace, that is what the length of the billet travel should be with the recuperator as against one without?

I noted that in the Sheet and Tube installation they increased the tonnage and that when they did the fuel consumption went up. To a certain extent as the tonnage increases the fuel consumption goes down and stays down over a considerable range. I would like to know where the turning point was and the reason for it; whether it was due to having to crowd the flame clear to the end of the furnace, and why the fuel consumption increased so abruptly.

C. Smith: I would like to ask what provisions they make for cleaning the recuperator?

Our experience has been, after running for a short time, the recuperator furnace passages clog up with soot, dust, etc.

W. Flanagan: One more question: I notice on that last slide showing the continuous furnace, the billets dropped off the skids onto the hearth. I assumed that was for the purpose of rolling them over. I wonder how much advantage there is in that instead of sliding them straight down the skids without turning them over.

F. G. Cutler: This is a rather important phase of our work. We have heard of boilers that have up to 90 per cent efficiency, and we all know at least those of us around the steel plants that the average heating furnace has an efficiency of considerably very much less than that, in a good many cases less than a third of that figure, and in view of the very unsatisfactory performance indicated by these figures, we should not let this opportunity go by without having as much discussion as possible.

W. Flanagan: Where you consider the limit for split firing or over and under firing, over straight over firing on a continuous type of furnace, what thickness of slabs or billets do you have?

Strickland Kneass: I can answer a couple of the questions. Those two furnaces on a 14-in. skelp mill replaced six small sand bottom furnaces, and our average coal consumption in that case was around, with the flat bottom, 430 pounds per ton. Since that time we have been running around 200, 225, on the Chapman Stein furnaces. That is purely a monthly figure of coal consumption. That takes in the entire heating up and cooling down period of the furnace. I think the other data which Mr. Buell gave in regard to the furnaces is absolutely correct in every way.

H. C. Seibert: Mr. Buell mentioned that there apparently is no limit to the degree to which we can preheat air. We all recognize the fact that the higher we preheat the air the more fuel we will save, the higher flame temperature we can get, the more economical will the heating be, etc. However, we also know that to maintain straight line heats on hot blast stoves, for instance, with good combustion efficiency on the stove, we need a very large amount of heating surface. For instance, to give you a rough comparison, some large furnaces of the continuous type require air perhaps at the rate of 20,000 cu. ft. per minute, which is about one-half of the volume of free air that comes through a blast stove of 100,000 sq. ft. of heating surface, not of the recuperative type, but of the regenerative type. The heat interchange between the gases and air being better in the regenerative than in the recuperative type in which you will always have differences between the two sides of the heated body.

Furthermore, we are always told in connection with fuel economies on furnaces, that before the change was made a fuel consumption of 500 pounds prevailed, which after the change dropped to 200 pounds. Thus we are left with the impression that the gain was due to the application of the recuperator. Such figures in many cases mean nothing. Very frequently the comparison is not made under parallel conditions. You find in digging up the history of such cases that it has been a matter of replacement of one type of furnace for another. It isn't fair to condemn any one furnace without giving us the true history of the case.

In experiments that we have made we find that every heating furnace has a hyperbolic characteristic somewhat like that shown below. In the curve the abscissa represent heating rate and the ordinates, the fuel rate. This curve shows that if we operate the furnace within a certain range of heating, we will get a very good fuel economy, but if we operate the

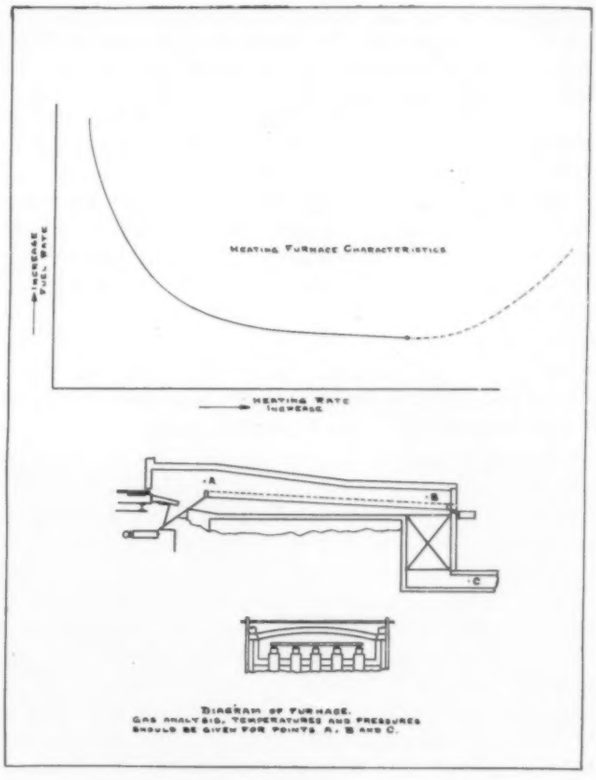


FIG. 1.

furnace at another point, it does not follow that we will get a good fuel economy. Likewise, after we pass a given rate of heating we will come to the point where the curve again rises and the fuel rate will be high.

Another thing in connection with furnaces, or any furnace for that matter, or perhaps we had better limit these remarks to the continuous furnace. If you bring in the mixture of fuel and air at the front, and not at too low a pressure, through air ports or gas ports which are not in the same plane, we will get a more or less imperfect mixture. Also will that mixture be less perfect the lower the pressure. While the higher the pressure and the nearer you introduce air and gas to each other the better will the mixture be and the higher the flame temperature. Numerous experiments show that the higher you go up in the pressure range, not necessarily in pounds but a matter of a few inches above atmosphere, makes a very remarkable difference in the state of combustion. I don't wish to knock recuperators or regenerators. All the experience I have personally had with recuperators is that we have not been able to eliminate leakage, and that is a very serious proposition. If you are putting in recuperators and preheating the air to a thousand deg. or 1500 deg., I don't know of one recuperator that will withstand such temperatures without leakage. You invariably lose pressure and volume at the introduction point (the burners) and when you do that you play havoc with the fuel rate.

We also heard of fuel rates of 120 pounds a ton. There is nothing phenomenal in that. Without the specification of pounds of coal per ton, without specifying the kind of steel, the thickness of the steel, particularly the thickness, and the length of the furnace, it can mislead one into false conclusions. A certain type of furnace heating steel of a certain thickness, heating at a certain rate, may give you 110 pounds, but if you double the thickness of the steel, even with the same tonnage you find you will not get the same fuel economy, because the furnace efficiency is going to drop. This is evident from the fact that a different thickness of steel requires a different time for the heat to penetrate it.

W. Dyrssen: I would like to ask Mr. Buell if he has made a complete heat balance on that continuous furnace with 180 pounds of coal? What percentage of the heat goes into the steel and how much was radiated from the different parts of the furnace; also how much heat appeared in the final gases going to the stack? I should also like to know the temperature of the air, of the combustion air at the burners and how it was measured.

W. de Fries: I would like to ask Mr. Siebert a question about the leakage on recuperative furnaces, to which he has just referred. I have had personal experience with both regenerative and recuperative furnaces and know that the former type is by no means free from leakage. Surely Mr. Siebert does not wish his remarks interpreted to mean that the regenerative furnace does not show any leakage whatsoever and I assume therefore, that it is the degree of leakage in the two different types of furnaces to which he had reference; perhaps he can give us some definite information about the relative percentage of leakage in the two types of furnaces referred to.

H. C. Seibert: I made no promises of leakage about regenerative types. I confined my remarks to leakage on the recuperative types.

W. C. Buell: How much less is it?

H. C. Seibert: Unless you gentlemen present some figures, we will not present ours. We have the figures.

W. C. Buell: In answer to Mr. Miller on the cost of upkeep, we have had one recuperator in operation for four years. That is the oldest one that we have in. No repairs have been made on this or any other. To date there has been no upkeep cost on any Chapman-Stein recuperators installed.

The gentleman from the Wheeling Steel Corporation has been satisfactorily answered by Mr. Kneass.

Answering Mr. Flanagan on the economical length, I will say that in designing any furnace you have got to set up conditions or rather you may be given conditions that you have to meet. On a basis of the knowledge that we have, we can premise the design of a furnace to meet any condition that we have to. In other words, we can go in length up to 50 feet or even more under some conditions. Our average length of furnaces is from 40 to 50 ft.; what we call effective heating lengths. Mr. Seibert has drawn a chart which will work in very well. In his example he shows very conclusively you have to design a furnace to meet certain conditions if you want economy. If you go beyond the range for which the furnace is designed, the fuel rate is going to run up. You can't help it. At low tonnage rates the radiation constant of your furnace is just the same as at higher rates. It takes so much heat to bring a given furnace up to 2100 or 2200 deg., and maintain it there, and then if you put one ton an hour through, the quantity of heat required for furnace maintenance is the same as if you put 10 tons through.

H. C. Seibert: In that connection, gentlemen, perhaps I had better amplify my previous remarks. Undoubtedly in every furnace the characteristic that I have shown exists, but I may have given false impressions as to the character of the curve. The curve as far as we have been able to trace it in actual working tests, really resembles the form of a hyperbola. It cannot continue towards its asymptote, however; it must rise at some point here, but we have never in any maximum rates of heating that we have been able to maintain — been able to find the point at which the curve begins to rise. There are certain limiting conditions, of course, to maximum rolling rates and to every working furnace. We haven't in any case determined this breaking point where the curve begins to again rise, but the curve as far as we have been able to trace it resembles that of the equilateral hyperbola.

W. C. Buell: Your low point is a factor of length.

H. C. Seibert: For a furnace of a given length you have that characteristic.

W. Flanagan: Then your recuperator will flatten that out over a non-recuperative, equalizing your stack losses due to that.

W. C. Buell: In answer to your next question — that we were able to get high tonnage and still maintain a fair fuel consumption was due to the fact that from much hotter furnaces we were able to return a very large proportion of the contained sensible heat back into the air and thus increase the flame temperature. It is a balanced condition. Take heat out of

your furnace and put it into the air, and you will increase the flame temperature.

A. L. Culbertson: In speaking about heat lost or carried away by the stack gases, it merely depends upon how large the recuperator may be as to what stack loss is obtained. Recuperators are designed to deliver stack gases at whatever temperature is desired. However, the cost of the added recuperator installation which is necessary to reduce the waste gas from six to 700 deg. down to atmospheric temperature would be excessive for the amount of benefit obtained.

The Chapman-Stein Furnace Company has a standard recuperator installation located at the Owens Bottle Company plant at Clarksburg, W. Va. Stack gases from this recuperator are delivered to a stack flue common to another furnace. This other furnace supplied sufficient heat to operate the stack and give the pull necessary for both installations. Since the recuperator did not have to supply heat for the stack, it was possible to determine how low a temperature could be obtained in the waste gas and still operate satisfactorily. In this case the waste gas left the recuperator at 267 deg. F. The air was preheated in the recuperator to 1450 deg. F.

W. C. Buell: In answer to Mr. Smith on the question of cleaning: Every one of our flue gas passes can be inspected and cleaned while the furnace is in operation. The flue gas passes, as you will remember, are in the horizontal plane. The gas passage is approximately nine inches square. Through the wall at the termination of each one of these passes is a loose brick which can be taken out and the recuperater cleaned.

Working under bad conditions with raw dusty gas, it seems that an annual cleaning will keep the recuperator in shape. We don't know of any case where more frequent cleaning has been necessary. Of course, you might find a condition where you had an extremely dusty product or pulverized coal, when non-frequent cleaning would be desirable. We always provide for an ample socket if we are working with any material which is liable to give slag, or excessive dust.

Mr. Flanagan asks about side discharge. Fig. 9 follows conventional practice. We generally run the skids down to what we call the reheating or flat hearth. The billet tips off of the skids there turning over, and they generally bar the billet towards the manipulator door.

W. Flanagan: Much advantage with that over the other way? (Through skids.)

W. C. Buell: I am inclined to believe that the skids could be run through, but I doubt if you would care to have it.

A. L. Culbertson: In answer to the question with reference to the straight drop from the skid pipes to the small soaking hearth in the side discharge furnace, this is done generally to effect the turning over of the billets or ingots as they drop off of the skids. While on the soaking hearth any slight cold spots which have been formed due to being in contact with the water-cooled skids up to that point are removed.

If the skid pipes were inclined instead of dropping straight down, the billet or ingot is liable to stop on or close to the skids and the manipulator used to discharge the ingot might possibly damage the skid pipes. A further point which is important is that in employing a split flame it is necessary to have the soaking hearth sufficiently low that the ingot or billet when resting upon the hearth will not obstruct the flow of gases under the steel on the skid pipes. If an incline is used occasionally the slab, billet or ingot will stop part way down and the flow of gases will then be obstructed.

A considerable saving of fuel is obtained on the side discharge furnace over that of the end discharge. This is due to several reasons. Side discharge furnaces are generally used where labor is not such an important item and a large number of men are utilized in charging and discharging, and it is found more in small plants than in large ones. On a side discharge furnace the charging door is generally shut except for the period of charging. This is one means of saving fuel. During temporary delays the billets on the skid pipes are sufficiently far removed to be free from injury by overheating. This makes unnecessary the checking of the whole furnace and the subsequent cooling off of the whole system which is absolutely necessary in case of an end discharge furnace where the billets extend clear through to the discharge point. The end discharge furnace is generally closed by means of flappers on the discharge end. These flappers are more or less open and the opening being below the furnace proper allows the inflow of cold air due to the stack action of the inclined discharge end of the furnace. This cold air entering the furnace, although not excessive when the furnace is operated under a slight pressure, is sufficient to run up the fuel costs somewhat.

It is seen for these reasons that a side discharge furnace is more economical in fuel and more flexible to operate than the end discharge furnace, however, the end discharge furnace is generally preferred in large plants, due to the saving in labor necessary to operate it.

W. C. Buell: We are using it on slabs down to about two and one-quarter inches thick. We recommend it wherever possible. There is considerable advantage in split flame firing. Again, there are certain classes of work that you can't split fire. Anything that will roll cannot be split fired.

A. L. Culbertson: While in England the speaker had occasion to test a furnace equipped with this type of recuperator and which was using a split flame method of firing and heating 14-in. to 17-in. square ingots. The fuel consumption obtained on that furnace was 105 lbs. of coal charged in the producer per gross ton of ingots heated. This is extraordinarily good efficiency and is due, we believe, not only to the efficiency of the recuperator but to the method of operating the furnace. This furnace was a side discharge continuous furnace and was operated with all doors closed except during charging and discharging. We would like to ask Mr. Siebert what percentage of his total number of furnaces are obtaining 120 lbs. of coal per ton and also how he explains this extraordinary high efficiency for a simple non-regenerative and non-recuperative furnace. These results are quite remarkable and better than anything we have ever heard of, let alone seen when using a simple furnace.

H. C. Siebert: We have perhaps a dozen continuous furnaces without preheated air, on cold air. It will run from 120 to 160, month after month.

A. L. Culbertson: About what percentage of that would be of the heating furnaces that you have?

H. C. Siebert: I don't know.

A. L. Culbertson: About how many furnaces you might have would be 120 pounds?

H. C. Siebert: They are all in one plant. That comes back to the qualifications that I made before, that with certain classes of steel, certain rates of heating and certain lengths of furnaces you can get 120 pounds, but with that same furnace, double the thickness of the steel, with the same rate of heating in tons per hour and you will not get 120 pounds. You can't get it.

A. L. Culbertson: Every furnace has to be designed for particular needs, and in some cases it is easier to secure good fuel rating than in others.

W. C. Buell: You said that was cold air proposition, producer fired?

H. C. Siebert: Yes. The furnace is operating within a few miles of this building. It will operate month in and month out with 50 per cent efficiency.

S. Kneass: Are those furnaces operating on producer gas or is that the equivalent value of some other kind of fuel?

H. C. Siebert: Operating on producer gas. You spoke of a furnace with a recuperative life of about four years. How did the recuperative efficiency vary during that period?

W. C. Buell: On tests we can find no change. There is no change as to leakage or transfer. That holds good in several cases.

H. C. Siebert: Could you give some analysis, Mr. Culbertson of the products of combustion entering the recuperator and the products leaving the recuperator?

W. C. Buell: They are the same practically.

H. C. Siebert: Then there is no leakage?

A. L. Culbertson: Before the Chapman-Stein recuperator was introduced in this country the speaker spent about two years in France, England and Italy investigating different installations built by the Stein Company of Paris. Considerable effort was made to find a recuperator which had deteriorated. A number were inspected which had been in operation for 10 years with no repairs, yet no change could be discovered in the operation.

One quite interesting installation was a forge furnace constructed within 50 feet of a large hammer. The vibration could be felt every time the hammer was operated yet this recuperator had been working there for eight years and no change was noticeable, nor had repairs been made. No tile could be found that had ever been broken or cracked. This same condition holds good as far as the 65 installations made in the United States are concerned. No repairs have as yet been made and some installations have been in operation for over three years.

W. C. Buell: I think that all of Mr. Siebert's questions have been answered with one exception. He states he has never seen air over 1500 deg. from a recuperator. We have some recuperators heating air to 2,000 deg. or more.

A. L. Culbertson: No leakage has yet been found in the recuperator due to short circuiting. The peep holes and end plugs which permit observation of the waste gas flues occasionally are not replaced tightly by the operator after making observations and a slight amount of air will then be drawn in by the stack pull through the end wall. If the plugs are mudded up properly this infiltration will be eliminated. As to leakage through the recuperator joints from the air flues into the waste gas flues or vice versa, none has been found as yet. The analysis of flue gas at the top and bottom of the recuperator which has been taken in many cases has shown no presence of oxygen with the exception of small amounts due to infiltration through the front wall observation plugs. When these were mudded up, no difference was noticeable in the analysis.

The principle upon which the Chapman-Stein recuperator is designed eliminates leakage. Due to the vertical air flues acting as stacks in themselves, there is a suction created in the air flues which draws in the air at the bottom of the recuperator and delivers it to the port under pressure. The flue gas passages adjacent to the air flues likewise are working under slight suction furnished by the stack proper. With a minus pressure in the air flues and likewise in the stack flues there will be no tendency toward leakage from one to the other if these minus pressures are the same. The design takes this into consideration and employs this balanced draft to eliminate leakage. Due to this principle in operation it is not necessary to cement the recuperator tile nor hold them rigidly together. Only their own weight is employed to insure tight joints with a small amount of ordinary fire clay used between the tile. Since all joints are horizontal, weight suffices to keep the joints tight. If air were blown into the recuperator under pressure there would be a considerable differential between the air and the waste gas pressures and the tendency to leak would be the sum of the plus and minus pressures. No fans or blowers are employed in the Chapman-Stein design thus allowing the balanced draft condition.

W. C. Buell: In answer to Mr. Dyrssen's question, I haven't the figures here I am sorry to say. We have a balance on some furnaces in the glass industry and I will be very glad to include that in the discussion when it is printed.

I might say that your CO_2 is exactly as you care to make it, within the usual limits. We work as the heater wishes to. In the steel industry they want to have a slight amount of CO showing in the fume. In the glass industry they work with a slight amount of O_2 showing. It depends a good deal on your operation as to what your flue gas composition should be, but set any composition of flue gas desired and we can maintain it.

The recuperator after it has once heated, works under constant condition of temperature. With a reversing furnace, every time it is reversed, there is a change in air temperature, between 200 or 300 deg. or perhaps more. But the recuperator works at the same air temperature. We have furnaces in the glass industry that are started and go along for a couple of years without being shut down. The air comes through with constant temperature. In such an operation as that, this is a very valuable feature because the reactions in glass making are within close limits.

I might say that we can take the fumeé at any condition you want to set up—1500 deg., 1800 deg., etc. — and we can return in the air practically any percentage of heat that the air will receive. Recuperator efficiency depends on what you care to pay for the recuperative structure.

H. C. Siebert: This is a very important subject, and I will plead for an extension of time if such a thing is possible. I think everybody in the industry realizes there are two points to the fuel situation—one,

that about half of the fuel is approximately used under boilers; and two, the other half for metallurgical furnaces.

You know that if we design boilers properly we can get decent efficiency. We can also make considerable strides in the improvement of furnaces. There are a few other points I would take up, so if it is possible to continue the discussion a few minutes longer, I am sure it will be appreciated.

F. G. Cutler: If there is no objection we will continue.

H. C. Siebert: The question of leakage has been found to be a very serious one in the past with recuperators, while it is true that these types were not of the Chapman-Stein type, I cannot see where the physical laws are any different in the Chapman-Stein type. For instance, we know that we get variations in operation daily, and especially weekly. Week-ends the heat is shut off, the furnaces cool. The larger we make the recuperator the more difficulty we will experience in unequal expansion and contraction. That being the case, we are bound to set up a distortion which sooner or later will bring about leakage, and if we pass into that recuperator partly combustible gases, at the point of leakage, combustion will take place and will tend to melt or fuse the recuperator and further distort it, and then you get a considerable leakage, and that is exactly what we have been up against in all forms of recuperators, whether of the brick type or tile or iron and steel tube type—all have shown the same thing—bad leakage.

While I recognize the value from the standpoint of leakage in the Chapman-Stein construction of trying to maintain a minimum pressure differential between the flue gas and air ports, even though that may be a tenth inch differential or less than that, if you please, but if you have several ten thousandths joints and get leakage through them, the aggregate leakage will be quite an item, and when you have it you are then robbing the furnace of the oxygen that is demanded at the burners, and if we have a lack of air at that point we will lose more at the burners than what we have gained in the recuperator.

W. C. Buell: The only thing that will give us information about leakage is a gas analysis apparatus. If that shows a change at recuperator inlet and outlet no greater than the error of the instrument, we naturally think it is tight. But beyond the error of the instrument, we have found little change. That is all I can say in answer to the question about leakage. There should be no leakage, for in the Chapman-Stein design, forced draft is not employed, and differential pressures between air and fumeé are very slight. Assume a tenth of an inch of differential and convert that into comparative terms from absolute pressure and the percentages of differential is so extremely small, that tendency to leak is almost nil. If, for the sake of argument, a crack develops in a tile—I don't admit that crack for I have never seen one, but if we do there is enough surface resistance set up in the crack to prevent the passage more than extremely small quantities of air or fumeé. The question of leakage is very unimportant to us and we ignore it entirely because there isn't or can't be any material leakage.

A. L. Culbertson: Mr. Siebert stated that the principle of the Chapman-Stein recuperator was not any different from that of other types. We cannot agree with him there. In all types of recuperator construction the result desired is, of course, to exchange heat from the waste gas to the air. The difference between the Chapman-Stein design and all others is that the Chapman-Stein recuperator employs a balanced draft with the same minus pressure in the air flues and stack flues to eliminate leakage, while in all other cases there is a considerable difference of pressure and the tendency to leak is very great, necessitating sealed joints and frequent resettings to eliminate the leakage which is bound to occur when the recuperator is heated and cooled, due to the shifting which is obtained by expansion and contraction.

Mr. Siebert mentions leakage in all recuperators with which he has had experience. We agree that, undoubtedly, he has found this condition. This condition was likewise found by us in all cases until we came across the Stein recuperator. This is primarily the reason why the Stein recuperator was introduced in the United States. Undoubtedly the shifting about and opening up of joints caused leakage for Mr. Siebert in the recuperators with which he has had experience. The Chapman-Stein recuperator is so designed that it can expand and contract. Any shifting which is obtained due to expansion or contraction is not detrimental to this recuperator. No attempt is made to tie the recuperator together tightly. It is allowed to expand. There are no joints except horizontal joints and the weight of the tile is sufficient to close the joint enough to eliminate any leakage inasmuch as there is no tendency to leak when the same minus pressure is on both sides of the joint. In this way the new design of balanced draft recuperator works toward eliminating troubles which formerly were always encountered.

The question of recuperator size was brought up. The size of a recuperator is determined by the amount of waste gas which must pass through it and the amount of heat which it is desired to recuperate. When extra large recuperators are necessary, several units are built, each unit consisting of a separate recuperator with a common wall between it and the next. The size of the recuperator as installed on the third and fourth furnaces constructed by the Chapman-Stein Furnace Company for the Youngstown Sheet and Tube Company at Youngstown, Ohio, is 10 ft. high, 22 ft. wide and 15 ft. long. This recuperator is divided into two units, each part being 11 feet wide.

W. de Fries: I believe Mr. Siebert has given us a very valuable explanation in connection with his statements about leakages on recuperators and their origin, by stating that partly combustible gases were present in the flue gas ducts and that their delayed combustion caused locally temperatures high enough to affect the material, from which his recuperators were made, to the point of fusion with subsequent distortion of the entire recuperator structure.

Such occurrences stress the necessity of burning all the fuel in recuperative furnaces over the hearth, or perhaps even before their entrance to this part of the furnace and apply the heat developed by its combustion to the steel and not to the recuperator; this is the one definite way of protecting the recuperator material and preventing its disintegration; incidentally, I may state that unburnt gases passing from the hearth confine their destructive influence not to the recuperators only but play havoc with the checkers in

regenerative furnaces just as well. I have seen many checkers melted and fused to a solid mass by delayed combustion.

Realizing then the need for quick and proper combustion, we have in the one way recuperative operated furnace the best possible opportunity for application of good and reliable fuel burners, whose use in the two-way regenerative furnace prohibits itself on account of the characteristics of this type of furnace, which requires the use of the fuel entrance passage as waste gas exit port.

Mr. Siebert just stated, that pressure on the incoming fuel and air supporting its combustion is a valuable aid in proper and efficient furnace operation; I agree with him absolutely on this point. After all, a recuperator is only an air preheater, which works best in connection with a good fuel burner; the vital feature of the recuperative furnace type is this: It makes the application of fuel burners, even automatic proportioning burners, possible; destruction of the recuperator and subsequent leakage is therefore not the fault of the recuperator, but merely indicates absence of proper combustion devices, without which no modern recuperative furnace is complete.

This brings us to the question: Which type of burner is best suited for recuperative furnace. Mr. Culbertson spoke about the low pressure differential in the Chapman-Stein recuperator in the waste gas and air passages respectively, pointing out the desirability of suction on the air equal to that on the waste gases produced by the stack; fortunately we have in every aspirating type of burner the very equipment, which complies with this requisite; the slight updraft on the air caused by the stack effect of the recuperator (or for that matter of any regenerator) is not enough to cause that type of combustion which Mr. Siebert mentioned as desirable. Considerably higher velocities and consequently pressures are necessary to obtain good results. The jet effect of high pressure fuels introduced through aspirating type burners, whose air inlet connects with the recuperator, at once gives us the high flame velocity and good mixture, which is so essential for the recuperator life and establishes that pressure equilibrium in the recuperator passages, which absolutely eliminates leakage through the absence of physical energy.

Mr. Siebert mentioned the leakage in the recuperator from the air to the waste gas passages as cause for air shortage to meet combustion requirements. I have just explained how sufficient air can be brought through the recuperator at all times; by sucking it in with a high pressure fuel jet; where high pressure inspirators such as furnished, for instance, by the Surface Combustion Company, are not or cannot be applied, sufficient air still can be delivered to the furnace port by making the recuperator air passages large enough to meet an anticipated leakage of from 10-15 per cent of the air entering the recuperator inlet; with other words, design the recuperator ample; naturally the recuperator efficiency is not as high under this latter condition, as it ought to be, but it is meeting with operating requirements.

The principle feature to keep in mind is this: that the recuperator is not intended to take up heat lost to the furnace by unburnt fuel as a sort of secondary combustion chamber; its sole object is to exchange heat otherwise wasted in the outgoing gases of an already completed combustion with the incoming air intended to support this combustion.

H. C. Siebert: There are only a few more points that I would like to bring out in connection with this very important subject. I can't get away from it. I think it is very unfortunate in view of the importance of the subject that we do not talk in definite terms. What we should do, and I would be mighty glad if the exponents of recuperators, or manufacturers of different furnace types would present some definite data in the form of analyses, so much fuel going in, such gas analyses, so many feet away from the burner, such gas analysis entering the recuperator and such an analysis leaving the recuperator, etc. This is the pressure entering and this is the pressure leaving. Temperatures, pressures and analysis, fuel rates, heating rates. When we have them we can talk intelligently on the subject.

W. C. Buell: On that question you just brought up, why should we tell you how much we are going to preheat the air and how hot the fumeé is going out? If we come to you with a definite guarantee that the furnace will heat your metal for 180 pounds of coal, isn't that sufficient? Let me add, however, that we are more than willing to give you any figures you wish.

H. C. Seibert: I couldn't accept such a fuel rate, unless I knew a little more about your conditions.

W. C. Buell: We are perfectly willing to show you furnaces in operation producing at this rate.

H. C. Seibert: The convincing thing to me would be this: Let us say at this discharge point, what is the state of combustion at this point; what is the state of combustion at that point; what is it as it leaves your gas going out; what is it here?

W. C. Buell: Why should you know these details? You don't want to design a furnace. You want to heat metal at a given fuel rate.

H. C. Seibert: We want a fuel rate, yes, but if at the same time you show us, it will be helpful.

A. L. Culbertson: Along that line, we would be glad to go into that and give you those figures if we had them available at the present time. Our company has been in business for about three years, during which time we have been very busy building furnaces rather than taking analyses and proving to engineers the state of our combustion. The thing we have proven definitely to all people that we have put in recuperators for is that we are saving them money and that is the thing that appeals to the party that is going to put up the money to buy the furnace. The data that we show them generally is the dollars and cents saving and we guarantee it. We have done so in every case. We have about 65 furnaces in operation. We haven't had time so far to get the various analyses of the fuel at the various points in the furnace mentioned by you for the simple reason that the people that want to buy these things want to get some money out rather than the analyses and as a result we have not made any effort to compile. We will be glad, however, to get into that and show you these things, too, as soon as we have a little more time. We are pretty busy right now building furnaces.

W. De Fries: In reply to Mr. Siebert's question I can say, that I completed day before yesterday tests on a small recuperative fired furnace operating on natural gas; the furnace is equipped with surface combustion high pressure inspirator burner and I can quote from memory the following figures, which may not be exact to a few hundredths of a per cent: Di-

rectly in front of the aspirating tube the combustion analysis showed 9.8 per cent CO_2, some CO as yet unburnt and some free O_2. Eighteen inches in front of the burner the combustion analysis showed 11.5 per cent CO_2; after passing through the hearth, the down takes and the first pass of the recuperator we found 10.7 per cent CO_2 and 10.5 per cent CO_2 in the third and last pass of the recuperator near to the stack. These analyses give a good indication that so far as leakage in the recuperator is concerned, there is nothing to speak of. On the other hand, the analysis also proves that all gas was burned in the furnace and nothing in the recuperator, because 18 inches from the burner we had the highest percentage of CO_2 which we could possibly obtain from our fuel.

W. Dyrssen: I think this is very appropriate and I am sorry that some of the questions have not been answered as well as the fact that the Chapman-Stein Company has not had time to make this investigation. I think that these questions are perfectly proper and we should know what the recuperator actually does.

A. L. Culbertson: This furnace located at the plant of the Imperial Glass Company, Bellaire, Ohio, was equipped with regenerators and was using 180,000 cubic feet of natural gas in 24 hours and giving an output of 39 pots of glass per week. The regenerators were removed and Chapman-Stein recuperators installed in their place, slightly changing the method of firing the furnace at the same time. When in operation once more, the fuel consumption was found to be 110,000 cubic feet of natural gas per day—a reduction of 70,000 over the regenerators. The output was stepped up to 56 pots of glass per week, showing an increased output of 17 pots per week with 70,000 cubic feet less gas per day. Analysis of the gases leaving the furnace when fired with producer gas was found to be 16.4 per cent CO_2 and .5 per cent oxygen. The temperature in the furnace obtained by optical pyrometer at its hottest point was shown to be 2810 deg. F. The waste gas leaving the furnace proper showed a temperature of 2550 deg. F. Entering the recuperator it was 2375 deg. F., the drop being due to the extra long flue leading from the furnace to the recuperator. The air for combustion was preheated in the recuperator to a temperature of 1950 deg. F. The waste gas leaving the recuperator analyzed the same as that which left the furnace.

We regret that we have not been able up to this time to obtain a complete heat balance; however we have a large number of analyses of waste gas leaving furnace and recuperators and temperatures throughout the whole system on many installations. So far these figures coupled with the very evident saving in fuel obtained and increased output evidenced have been sufficient for those investigating the Chapman-Stein recuperator. In the near future, however, we expect to run a complete heat balance test on a continuous furnace for our own information, and to those who desire it we will gladly furnish copies.

Ordinarily it suffices to examine the condition of the waste gas leaving the furnace and leaving the recuperator, also show temperatures of the air entering recuperator and leaving it in the preheated state where it is under slight pressure and high temperatures.

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*Some Applications of Oxygen to Ferrous Metallurgy**

By F. W. DAVIS†

THE fact that the Association of Iron & Steel Electrical Engineers is holding a "Fuel Saving Conference" is evidence that the steel industry recognizes the increasing importance to the industry of this subject, and the necessity of joining forces to better solve the problems arising from the increasing cost and decreasing supply of our available fuels. It is both fitting and proper when considering means of effecting greater fuel efficiency that the value of using oxygen or oxygen enriched air for combustion be recognized. You gentlemen of the steel industry spare no pains to secure a coal with as small a content of inert matter or ash content as possible. You recognize that each one per cent of ash in coal represents a financial loss to your company. Is it not then also essential that you consider the use of oxygen enriched air for combustion? The combustion of 1 pound of carbon to carbon monoxide requires 1.33 pounds of oxygen and to carbon dioxide requires 2.66 pounds of oxygen. Speaking in terms of natural air, for each pound of carbon to CO you use 5.75 pounds and to CO_2 11.5 pounds of air carrying 77 per cent inert matter.

The matter of using oxygen enriched air has received much discussion, but as yet very little progress has been made in practical application. Experiments were conducted in Belgium just previous to the war in which oxygen enriched blast was applied to the iron blast furnace. Little information has been published regarding the results of this work, in fact, it is quite possible that conclusive results were not obtained from the short test.

No doubt the greatest single factor in preventing development along lines of oxygen enrichment has been the high cost of oxygen. In view of the many recent developments in oxygen manufacture, and considering the increasing cost and decreasing quality of our raw materials, the Bureau of Mines, Department of the Interior, has undertaken an investigation of the application of oxygen or oxygenated air to the metallurgical processes for consideration, and appointed an Advisory Committee to study the problem.

The work of this committee was divided into two parts, as follows:

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†Metallurgist, Department of the Interior, Bureau of Mines, Washington, D. C.

1. Study of present day processes for the production of oxygen, in order to determine the feasibility of attempting to produce oxygen, or oxygenated air, in such amounts and at such a cost as to permit of its use in metallurgical operations.

2. A study of the feasibility of using oxygen, or oxygenated air, in metallurgical operations in order to increase the efficiency of same, and thus bring about the production of metals at a lower cost and possibly the use of lower grade ore.

The results of the theoretical study of problem No. 2 have been published by the Bureau as Serial No. 2502 Reports of Investigations, and may be secured by request. No detailed report of study No. 1 has been published, although much has been accomplished. An extract from the metallurgical report regarding the cost of the oxygen is as follows:

> "This committee has made a thorough survey of the existing processes for manufacture of 99 per cent oxygen. The conclusions reached by this survey are that the comparatively small demand for the product has prevented the installation of large units suitable for metallurgical processes, with corresponding economies, and by far the greater proportion of the present cost of oxygen represents the cost of transportation, storage and service. Large oxygen manufacturing plants can be built to serve metallurgical purposes directly, which, by virtue of their large production and correspondingly increased efficiency, together with the fact that no compression in cylinders, storage, transportation, or service will be required, will be capable of delivering oxygen for the processes at a cost not to exceed $3 per gross ton. In other words, the committee finds that the oxygen industry is now able to make plants for supplying large quantities of oxygen to metallurgical industries at low cost."

Application of Oxygen to Metallurgical Processes —Blast Furnace Manufacture of Pig Iron.

The matter of increasing the oxygen content of the air blown into the iron blast furnace has probably received more discussion than any other proposed metallurgical application. The fact, however, that oxygen has always been an expensive commodity has done much to prevent any real analysis being made of the effect of this practice, so that published opinions, being opinions only, differ greatly from one another as to the ultimate result predicted. However, by a careful analysis of both the metallurgical and thermodynamic principles involved, one may predict with some accuracy the effect on furnace operation of a change of this character.

For a comprehensive study we must first consider the furnace itself, and the principal chemical reactions which take place therein. In every blast furnace there are two main sections, namely the hearth and bosh section, and the shaft section, each of which has a separate and distinct function to perform. The burden or charge as it passes down the shaft section, is heated by the ascending hot gases; the limestone is calcined, and the iron oxides are reduced to metallic iron by the action of the hot carbon monoxide. All of the chemical reactions of the shaft section are performed at comparatively low temperatures. In the hearth and bosh section, the slag forming materials are melted, the silicon is reduced, and any remaining iron oxide is reduced. In other words, the actual smelting is performed in the hearth and bosh section, and must be done at a very high temperature. Therefore, these two sections of the furnace must be considered as two individual units, the shaft or the preparatory zone, and the hearth and bosh or the smelting zone.

With this idea of the division of work performed in the furnace, it is well to consider the thermodynamic principles involved. The laws of thermodynamics apply to the blast-furnace just as much as they do to the steam engine, and for our purpose they may be stated as follows:

1. The quantity of work produced by transformation of heat bears a definite and unchanging ratio to the quantity of heat transformed.

2. The proportion of any given quantity of heat which can be utilized for conversion into work depends upon the temperatures at which the heat is applied and discharged.

Johnson* has stated the thermodynamic principle of a blast-furnace operation as follows:

> "For every set of furnace conditions there is a critical temperature above which only certain necessary operations of this process may be carried out. That is, the temperature necessary to melt the cinder and make it sufficiently fluid to perform its proper functions is the critical temperature, since the slag must be brought to this temperature, and the final reduction of the ore and probably other reactions must be performed by heat available above this temperature. The heat available above the critical temperature is the total heat of combustion of the carbon to carbon monoxide, plus sensible heat in the blast, less the heat necessary to bring the products of combustion to the critical temperature." To this should be added the sensible heat of the carbon at the critical temperature.

The truth of this thermodynamic law as applied to the blast-furnace has been demonstrated beyond question, first by the effect of preheating the blast, and later by drying the blast. For instance, with the introduction of hot blast, the fuel consumption of hard coal furnaces was reduced by more than half, although the actual increase in total heat was only about 18 per cent.

The application of air enriched with oxygen to the blast-furnace will be accompanied to a more or less degree by a condition similar to that effected by heating the blast — that is, the available heat for the high temperature work of the hearth and bosh section will be increased, for with each increase of oxygen we will have a corresponding decrease in the nitrogen to be heated to the critical temperature, and this increase in heat will be accompanied by greater smelting power of the furnace per unit of fuel and per unit of time.

In heating the blast, we increase the smelting capacity or available heat of the hearth and bosh without necessarily changing the heat of the shaft. With the application of oxygen to the blast, however, we will decrease the shaft or low-temperature heat as we increase the hearth and bosh heat, due to the fact that we are decreasing the quantity of hot nitrogen flowing through the shaft. The enriched gas, however, having a greater concentration of carbon monoxide will have a greater reducing power per unit of carbon, and we should expect to find that our shaft operation would be more efficient.

*J. E. Johnson, Jr., Principles, Operation, and Products of the Blast Furnace, 1918, p. 34.

It is useless to theorize on the effect of any change in blast-furnace operation without detailed calculations showing the action throughout the entire process of the material charged. For that reason data have been taken from a problem by the late J. W. Richards† from a blast furnace running on Lake Superior ore and heat and material balances prepared as follows:

†J. W. Richards, Metallurgical Calculations, Part II, Problem 57, pp. 294-295.

TABLE NO. I — CHARGES PER 100 LB. COKE

Weight Lbs.	Composition		Weight Charged Lb.	Pig Iron Lb.		Slag Lb.		Gases Lb.
Coke	C	88.0	88.0	4.4				83.6
100	SiO_2	5.3	5.3		SiO_2	5.3		
	CaO	5.3	5.3		CaO	5.3		
	H_2O	1.0	1.0				H_2O	1.0
Ore	Fe_2O_3	76.5	150.0	105.0			O_2	45.0
196	SiO_2	10.0	19.6	1.1	SiO_2	17.6	O_2	1.2
	Al_2O_3	3.5	6.90		Al_2O_3	6.86		
	H_2O	10.0	19.6				H_2O	19.6
Limestone	CaO	47.6	23.3		CaO	23.3		
49	MgO	4.8	2.4		MgO	2.4		
	SiO_2	5.0	2.5		SiO_2	2.5		
	CO_2	42.6	20.8				CO_2	20.8
Blast	O_2	22.8	100.5				O_2	100.5
440.7	N_2	76.1	335.4				N_2	335.4
	H_2O	1.1	4.8				H_2	0.5
							O_2	4.3

Pig Iron, 110.5lb. Slag, 64.4 lb.

Product per day, tons pig iron	358
Temperature of blast, deg. F. and deg. C.	720–382
Temperature of top gas, deg. F. and deg. C.	538–281
Heat in one unit of pig iron, cal.	325
Heat in one unit of slag, cal.	525
Cooling water heated per day through 50 deg. C., gallon	300,000

Assuming a critical temperature of 2740 deg. F. (1504 deg. C.), which is consistent with average practice, Table III shows heat balances of the hearth and bosh, and shaft sections, respectively.

From the above heat balance it is apparent that to smelt 110.5 lb. of iron of this grade, in the time specified, requires 104,447 Btu. at a temperature of 2740 deg. F. (1504 deg. C.) or more. It is also logical to assume that any change in furnace operation, such as the addition of oxygen to the blast which will increase the available heat in the bosh section, will increase the smelting power of the furnace in direct proportion to the additional available heat. On investigation of the thermal possibilities of enriching the blast in this particular practice with oxygen, we have obtained the figures in Table IV of available hearth or smelting heat and temperature, which are also shown graphically on Fig. 1.

The use of oxygen will not necessarily effect a speeding up of the operation as a whole. The smelting ability will be increased in proportion to the oxygen concentration, the preparing ability or the capacity of the shaft to perform its functions will not be effected in a like manner. Fortunately for the introduction of oxygen, our present shaft heat is in excess of requirements and the chemical work may be slightly increased over today's practice, so that it will be possible by the application of blasts moderately enriched in oxygen to increase the smelting ability of the furnace as a whole. To obtain full benefits of higher

TABLE NO. 2.

BLAST FURNACE MAKING PIG IRON USING ATMOSPHERIC AIR BLAST & STOVES

ITEM	HEARTH & BOSH							SHAFT														
	LB. OF HEARTH & BOSH	TEMPERATURE AT ENTRANCE °F.	HEAT PER LB. AT ENTRANCE B.T.U.	HEAT OF COMBUSTION PER LB. B.T.U.	TOTAL HEAT TO HEARTH & BOSH B.T.U.	TEMPERATURE AT EXIT °F.	HEAT PER LB. AT EXIT, B.T.U.	TOTAL HEAT CONSUMED FROM SECTION BY GAS B.T.U.	AT TOP OF BOSH, LB.	RELEASED IN SHAFT, LB.	TOP GAS, LB. H_2	TOP GAS, LB. CO	TOP GAS, LB. CO_2	TOP GAS, LB. H_2O	TOTAL LB. GAS.	B.T.U. IN GAS PER LB. AT 60°F.	HEAT IN TOP GAS, B.T.U.	HEAT OF COMBUSTION, B.T.U.	HEAT AT ENT. HOB TO SHAFT, B.T.U.	TOTAL HEAT TO SHAFT, B.T.U.	CU. FT. GAS AT 60°F.	% VOLUME OF GAS
O_2-FROM BLAST (DRY)	100.5	700	157		15770																	
O_2-TOTAL FROM BLAST (MOIST)	104.8																					
C- BURNED BY O_2 OF BLAST	76.6			4325	343875																	
C-IN IRON & LOST IN HEARTH	3.0																					
C-FOR REDUCTION OF Fe.	0.9																					
C-TOTAL TO HEARTH	84.5	2140	1431		95570																	
C-TOTAL CHARGED	88.0																					
C-BURNED IN SHAFT	3.5																					
CO- PRODUCED IN H & B	185.5					2740	732	135 786	185.5										135 786	135 786		
N_2- FROM BLAST	335.4	700	100		60370	2740	732	245513	335.4		335.4				335.4	118	39577		245513	245513	4545	64.1
H_2O-FROM BLAST	4.8	700	360		1728																	
H_2- FROM H_2O IN BLAST	0.5			52250	46125	2740	1280	3450	0.5					0.5	0.5	1053	526		3450	3450	94	1.3
O_2- FROM H_2O IN BLAST	4.3																					
H_2O- IN CHARGE	20.6													20.6	20.6	2275	4086					
O_2 - FROM Fe_2O_3										45.0												
O_2- FOR C BURNED IN SHAFT										4.6								3281		15092		
O_2- NET FOR CO										40.4												
CO- IN HEARTH GAS									185.5	0.1												
CO OXIDIZED BY NET O_2										74.7								4375		30831		
CO- REMAINING												129.9			129.9	118.	14502				1664	29.4
CO_2- FROM CO + O_2										111.1												
CO_2- FROM STONE										20.0												
CO_2- TOTAL													131.9		131.9	131.9	13981				1130	15.3

TOTAL HEARTH & BOSH HEAT 491196 306749

HEAT TO SHAFT 386749

NET AVAILABLE HEAT 104447 B.T.U.

73762 SENSIBLE HEAT IN GAS

NET SHAFT HEAT 73572 (637381 B.T.U.)

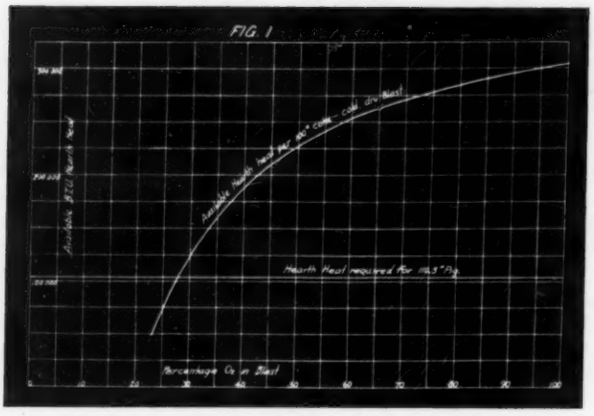

FIG. 1.

oxygen blasts, however, it will probably be necessary to change materially furnace design and practice. This is not surprising when we consider that our furnace of today is an evolution of a process built up around the principle of combustion by an oxygen mixture containing 77 per cent inert matter.

TABLE NO. III.

Heat Distribution — Hearth and Bosh.	
Latent heat of slag formation (63.4 × 945) — 49,900....	10,013
Latent heat of iron (110.5 × 126).....	13,923
Reduction of 5 per cent of Fe_2O_3 (assumed).....	17,000
Reduction of SiO_2 (2.3 × 4130).....	9,500
Cooling water	29,300
Radiation and conduction (by difference).....	24,711
	104,447

Heat Distribution — Shaft	
Heating coke to 2740 deg. F. (1504 deg. C.).....	95,570
Reduction 95 per cent of Fe_2O_3 (0.95 × 105 × 3140)...	313,494
Calcining limestone (20.18 × 1830).....	38,050
Heating slag materials to critical temperature.....	49,900
Heating iron to critical temperature (106.1 × 461).....	48,900
Evaporation of water in charges 20.6 × 1092.....	24,480
Radiation, etc. (by difference).....	69,187
	637,581

TABLE NO. IV.

Blast by weight.		Hearth heat available above 2740°F. (Btu.)	Increase (Per cent)
Natural air at 382°C.		104,447	
O_2%	N_2% (dry at 15°C.)		
30	70	124,855	21
40	60	188,589	83
50	50	226,945	121
60	40	254,492	145
70	30	270,792	163
80	20	284,481	177
90	10	295,168	187
100	.. ..	303,659	195

In order to show the probable effects of moderate oxygen additions, the following charts have been prepared on the basis of a blast containing 31 per cent oxygen by weight. In this practice it is proposed to eliminate entirely the hot blast stoves, releasing thereby for other use about 40 per cent of the total top gas produced, and, at the same time, giving the operator a more positive control of his high temperature heat than was ever possible with hot blast. Table No. 5 gives the material and thermal balance and Table No. 6 the heat distribution for this process.

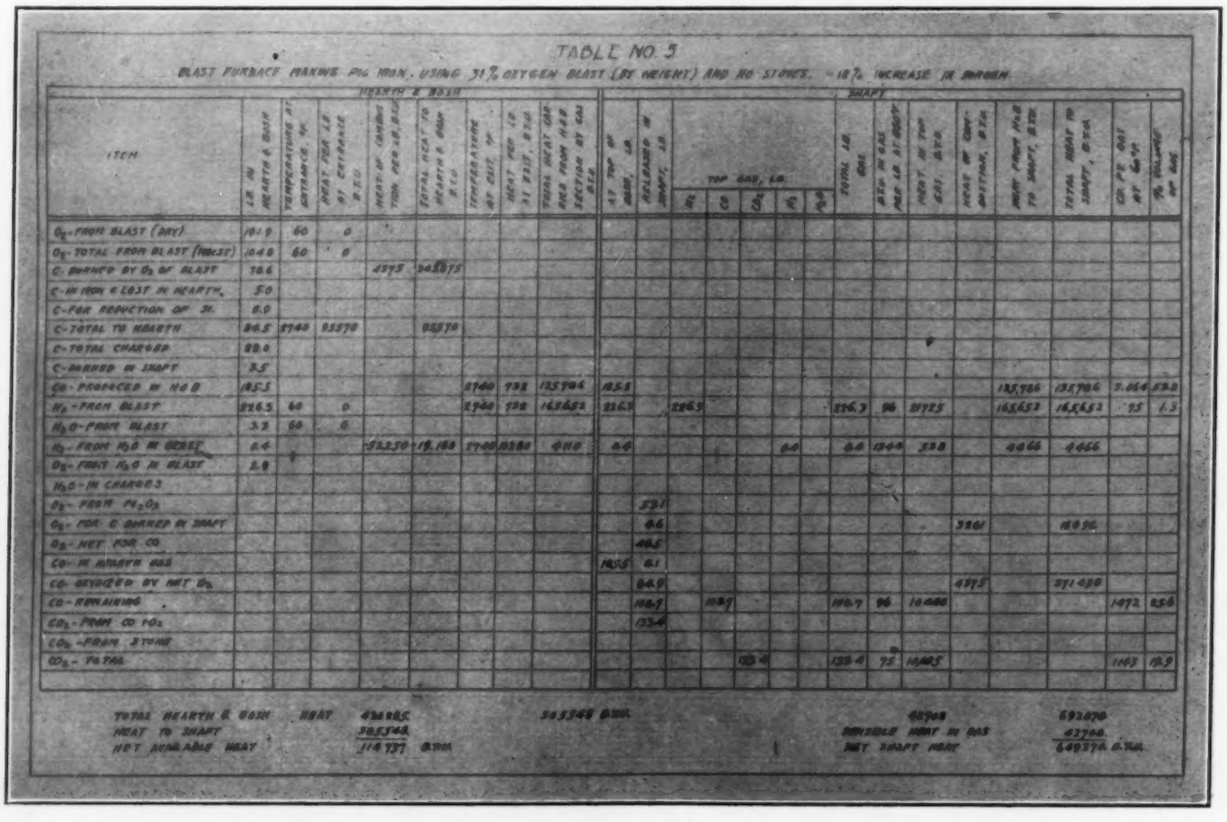
TABLE NO. 5

BLAST FURNACE MAKING PIG IRON, USING 31% OXYGEN BLAST (BY WEIGHT) AND NO STOVES. 18% INCREASE IN BURDEN

TABLE NO. VI.

Heat Distribution — Hearth and Bosh

	B.T.U.
Latent heat of slag formation (1.18 × 10,031)	11,800
Latent heat of iron (1.18 × 13,923)	16,420
Reduction of 5 per cent of Fe_2O_3 (1.18 × 17,000)	20,070
Reduction of SiO_2 (1.18 × 9,500)	11,210
Cooling water, radiation and conduction	55,237
	114,737

Heat Distribution — Shaft

	B.T.U.
Heating coke to 2750 deg. F. (1504 deg. C.)	95,570
Reduction of Fe_2O_3 (1.18 × 313,494)	369,923
Heating slag forming materials to 2740 deg. F. (1.18 × 49,900)	58,900
Heating iron to 2740 deg. F. (1.18 × 48,900)	57,720
Radiation from previous figure	69,000
	651,113

The figures show a deficiency of 1,743 Btu. in shaft heat. However, the same amount of radiation is assumed for this study as for the last, while the top will be considerably cooler, also the gas is assumed as excaping at 450 deg. F. It will probably be found that the top gas will be cooler than this.

In order to give an idea of the value of such a process to the industry, the following comparison of costs have been prepared; but in considering these figures it is well to bear in mind that they are based on the use of enriched blast in a furnace designed for atmospheric air, and that to obtain the greatest benefits from the application of oxygen to the process we shall probably be obliged to change the furnace design.

	Air Through Stoves.			31% O_2 Blast—No Stoves.		
	Lb. per ton.	Cost per ton.	Cost per ton iron.	Lb. per ton.	Cost per ton.	Cost per ton iron.
Iron ore..	3973	$6.00	$10.638	3973	$6.00	$10.638
Coke	2027	10.00	10.130	1717	10.00	8.585
Limestone.	993	1.25	.554	572	4.00 (calcined)	1.021
Labor:						
Supt., foreman, etc.			.047			.038
Stocking			.010			.010
Charging			.106			.106
Casting			.253			.204
Other producing labor			.009			.009
Repairs and supplies			.459			.372
Steam			.004			.003
Blowing			.400			.239
Water			.090			.073
Hydraulic power and pneumatic power			.009			.007
Electric light and power			.015			.012
Yard switching			.291			.291
Handling material			.200			.200
Chemical laboratory			.023			.019
General works			.044			.036
Safety and welfare			.006			.005
Contingent fund			.010			.008
Relining fund and depreciation			.650			.526
Interest on investment			.688			.583
Oxygen			...	572		.762
Gross total cost			24.636			23.747
Credit for surplus gas, 97,883 cu. ft. at 2c per 1000		$1.958		98,865 cu. ft. at 2.3c per 1000 (See note)		$2.274 .357
Credit for stoves		....				
Total credits		1.958				2.631
Net cost per ton		22.678				21.116
Saving per ton						1.562
Per cent saving						6.7%

358 tons per day	422 tons per day
	18% increase in production
Cost of stoves	$500,000
Depreciation per year.	5%
Int. on investment	6%
Yearly charge	55,000
Yearly tonnage	154,030
Charge per ton	0.357

One item, not included in the cost estimate but which will be a big factor in the saving effected by having oxygen available, is as follows: All furnaces are using more coke per ton of iron than the actual minimum amount required, this additional coke being their insurance against trouble. It is not uncommon to have a furnace running normally with a good grade of product, when suddenly with no apparent reason, the hearth section begins to chill, the slag becomes black and the furnace is in trouble. The only relief available for conditions of this kind is more heat in the hearth and bosh section, which heat can be secured only by the combustion of additional coke in this section. Coke requires from 12 to 15 hours to reach this zone after being charged in normal operation. The chilling of the hearth is progressive and may prevent regular tapping; if so, the time required for the extra coke to reach the seat of the trouble is increased and in many cases it is almost impossible to prevent a complete freezing up of the furnace.

To prevent this condition of affairs the furnace operator of today is always charging more than the theoretical amount of coke, so that when an emergency of this nature arises he has a reserve supply of heat to help counteract the chilling until he can effect relief. This additional amount of coke may be considered as insurance against trouble, and considered in that light is a good investment.

Now let us assume that the operator is using a blast which is a mixture of oxygen and air, the amount of oxygen being regulated at will. If in this case his hearth begins to chill, all he must do is increase the oxygen content of the blast, and he will immediately increase the available high-temperature heat in the combustion zone. He will be enabled to decrease his coke consumption to the minimum amount required, knowing that as his requirements change in the lower and formerly inaccessible part of the furnace, he can, by the addition of more oxygen, increase the amount of heat in that zone and effect immediate relief.

The actual amount of coke charged in excess of the minimum requirements will vary in different plants and under different management, so that no estimate can be made as to its magnitude. However, taken collectively, it represents millions of tons of coke consumed by the industry each year.

Another factor in the industry to be affected by oxygenated blast will be that of chemical control of the process. It is known that the available hearth heat exerts a great influence on the chemical composition of the product. This is demonstrated by the fact that furnace irregularities in the nature of hearth-heat deficiencies are accompanied by "off-grade" iron. A slight increase in humidity will often cause a furnace to produce high-sulphur iron. With a positive control of this hearth temperature, any irregularity could be checked before it had progressed far enough to show in the product, and it is believed that with the use of oxygenated blast a much closer chemical control will be attained than has been previously considered possible.

At this point it may be well to mention what would probably be the effect of oxygenated blast on the absorption of sulphur by iron. Powell*, in his paper "Forms of Sulphur in Coke, and Their Relations to Blast-Furnace Reactions", states that the major portions of the sulphur in the finished iron is absorbed from sulphur vapor by the spongy iron; and inasmuch as the pressure of this free sulphur vapor is independent of the amount of sulphur contained in the coke, the amount of sulphur absorbed by the iron will be independent of the sulphur content of the coke, but proportional to the speed with which the ferrous sulphide formed at the surface diffuses to the center of the iron. During a discussion* of this paper, Mr. Powell stated that the absorption of sulphur by the iron will also be proportional to the length of time the iron is subjected to the action of free sulphur vapor in this zone, or that the absorption of sulphur by the iron is inversely proportional to the velocity of the iron in passing through the spongy zone. Now, as we increase the oxygen in the blast, we are increasing production and hence decreasing the length of time that the iron will be in the spongy state. In the particular example previously given, we will increase the speed by 18 per cent, which should reduce the sulphur content of the product by 18 per cent. This is a factor of great importance for not only will it enable us to produce an iron uniformly low in sulphur, but it should also make available large quantities of coke, the high sulphur content of which prohibits its use in present-day practice.

Results to be Expected from Use of Oxygenated Air.

On the whole, our study of this problem has firmly convinced us that with the application of oxygen to the present blast-furnace we will accomplish the following results:

1. Decrease of production costs:
   a. By increasing the high temperature or smelting heat available per unit of fuel.
   b. By removing the necessity for charging more coke than is theoretically necessary.
   c. By rendering hot blast unnecessary, and reducing the initial investment by the cost of hot-blast stoves, at the same time releasing for other use the gas consumed for this purpose.
2. Increase in the present output per furnace.
3. Increase of flexibility of the process, by giving the operator a remedy for any irregularity or trouble occuring in the hearth and bosh section.
4. Increase in uniformity of product, by admitting of much closer chemical control.
5. A change in the limiting factor of the process from the inaccessible hearth and bosh section to the shaft section. This will mean that in the new process, any economy accomplished in the shaft section will be effective in increasing production and efficiency.
6. Make possible the use of cheaper materials, ore of a lower iron content, and coke higher in ash.
7. In addition to the above, it is believed that the sulphur content of the iron would be reduced by this practice, or, in other words, that we might use a coke higher in sulphur than is today possible.

The Bessemer Converter.

The Bessemer process for the manufacture of steel is another field in which the application of oxygen offers particular promise. This process as you know depends for its operation on the fact that when air is blown through a bath of molten pig iron, the impurities of the iron, carbon, manganese, silicon and in some cases phosphorus are oxidized leaving as a product comparatively pure iron. The heat for the process being supplied by the combustion of the impurities oxidized. The acid Bessemer operator pays rather heavily for sufficient silicon in iron to supply this heat and the basic Bessemer process is not practiced in this country because of our lack of ores sufficiently high in phosphorus to give a pig iron with sufficient of this ingredient to supply the necessary heat.

With oxygen available for use in the blast the operator may regulate at will the amount of heat retained in his converter, by simply decreasing or increasing the heat carried away in the converter gases. This is to be accomplished by decreasing the amount of inert nitrogen passing through and cooling the bath. Such a process will broaden the scope of the Bessemer process to such an extent that practically all grades of pig iron will be applicable to such refinement. It will further give the operator such a position temperature control as to enable him to make a product almost equalling present open hearth steel in quality at a cost which cannot be approximated in the latter process.

The Open Hearth Manufacture of Steel.

The open hearth process will no doubt be greatly effected by available cheap oxygen. It would be extremely difficult at this time, however, to predict either the extent or the manner in which the process will be changed. When considering the application of oxygen to any pyrometallurgical process the first thought is the increase in available temperature possible. In the open hearth the necessary heat for the process is imparted to the bath by radiation and conduction from a high temperature flame. The rate of this heat transfer is governed, other factors being equal, by the difference in temperature between the bath and the flame. It becomes obvious therefore that should we increase the flame temperature above present practice by the use of oxygen, the speed and efficiency of the process would be increased.

Unfortunately, however, there is another very essential factor which must be considered in this connection, namely, refractories. The refractories in present use are subjected to thermal conditions only slightly lower than their point of failure. We must therefore, before considering any material increase in flame temperature do one of two things, either we must secure more suitable refractories, or else we must change the design of our furnaces in such a manner as to give the refractories now available more protection from direct flame action.

In present practice we obtain high flame temperatures by heating the air and gas prior to combustion. The matter of using cold gas and cold oxygen enriched air to obtain the same temperature has been considered. This may be done, and would mean the

*Alfred R. Powell, "Forms of Sulphur in Coke, and their Relation to Blast-Furnace Reaction", Trans. A. I. M. E., 1923, pp. 587.

*Discussion of paper by Dr. Alfred R. Powell, "Form of Sulphur in Coke and their Relation to Blast-Furnace Reactions," Transactions A. I. M. E., 1923, pp. 603.

elimination of all checker work. The sensible heat in the outgoing gases could be recovered as steam in waste heat boilers. This process was considered by the committee, and a thermal analysis made. Also, a German patent has recently been granted on an almost identical proposition, the inventor proposing to use the steam generated to manufacture oxygen for the process.

There is no doubt that a modification which would eliminate regenerators would be welcome to the operator. However, is this modification sound? To make just an approximate comparison let us consider the two processes. In either case the furnace temperature will be limited by the refractories. Using refractories now available and present furnace design, no higher temperature would be permissible, so that the temperature difference being flame and bath would be substantially the same in either practice. This being true, and other factors equal, the amount of heat utilized in the furnace would be proportional to the volume of hot gas. When using oxygen enriched air without checkers the amount of hot gases per unit of fuel would be less than in the case of present practice with ordinary air. The amount of heat possible to impart to the bath per unit of fuel would therefore be actually less with the proposed process. True, a greater portion of the total heat would be recovered, but this would be in the form of steam and not as steel. It would seem, therefore, that until we have furnaces which would permit of much higher temperatures such a process would not be commercially practical.

It is believed that one of the initial applications of oxygen to the open hearth might be for chemical rather than thermal effect. Iron ore is used in present practice as an oxidizing agent. The addition of ore tends to cool the bath by the endothermic reaction between iron oxide and carbon, increasing thereby the time requirement of the process. In addition to this, any impurities contained in the ore will enter the bath. It has been demonstrated on a small scale that the oxidation of the bath may be accomplished by gaseous oxygen. The reaction involved would be exothermic and by increasing the bath temperature would materially shorten the time of the process. No additional impurities would be introduced with the oxygen.

It is further believed that with the use of oxygen for combustion with an excess of fuel gas a slightly reducing flame of the required temperature might be maintained. This would make possible the finishing of the steel under reducing conditions and a reducing slag, and should result in a product approaching electric steel in purity.

With the foregoing considerations in view, I have outlined as follows a tentative process which will be cheaper, will reduce the time requirements by one third and will produce a higher quality product.

1. Charge furnace in usual manner, using limestone, scrap, and pig iron in the solid or molten state according to conditions.

2. Melt down bath and test for carbon. The melting down period might be shortened by judicious use of oxygen in small quantities.

3. Add sufficient oxygen gas to replace usual ore additions, through iron pipes immersed in bath at each door.

4. Stir bath with rods and secure preliminary test for quick analysis of carbon, sulphur, and phosphorus.

5. Add more oxygen, if found necessary by tests.

6. Tap slag, at same time shutting off air supply to furnace; leave gas on and admit sufficient oxygen through ports to maintain temperature, but with gas passing through furnace only partly burned.

7. Charge more limestone and some sand to make second slag.

8. Treat slag with coke until it is partly converted to carbide.

9. If any alloys are to be added, they should be added at this point, with the exception of silicon or other acid-forming elements.

10. After bath has been alternately agitated by stirring and allowed to settle, and the metal is considered to be in a very clean condition, tap and treat steel in usual manner.

A discussion of the use of oxygen in the open hearth would be incomplete without mention of fuels. In this connection we have several possibilities. In the first place it will be possible to greatly increase the calorific value of producer gas by substituting a mixture of oxygen and steam for the air blast now used. It has been estimated that this process would produce a gas of about 400 Btu. per cu. ft.

Another consideration which to me appears of even greater promise and importance is the fact that oxygen should make available for open hearth use many of the lower grade and undesirable fuels. For instance, blast furnace gas is entirely unsuited for open hearth service. Its calorific intensity is too low. If however, we burn blast furnace gas in oxygen enriched air the temperature may be regulated at will, with a limit well above that of present furnace practice. The possibility of making gas from low grade coal, coke breeze and lignite, should not be overlooked. I believe that all of these materials would by the use of oxygen make a gas of open hearth quality. Such developments would effect great improvement in our present fuel situation.

It might be of interest to note that a plant is being constructed in New England for the manufacture of oxygen steam producer gas. This gas is to be used for domestic purposes to replace the water gas now so generally used. I was recently informed by a representative of the firm responsible for this development that they hoped to be in operation within the next six months.

The Manufacture of Ferro-Alloys.

The field of ferro-alloys is one of particular promise in the application of oxygen to combustion. So far, only a few of the ferro-alloys respond to blast-furnace reduction because of the inability of this type of furnace to supply the high temperature heat required. Consequently, electric-furnace processes have been necessary for the industrial production of all but three of the common alloys, and as is true with all electric-furnace processes, the cost of production is very high. Ferro-manganese, ferro-chrome, and low-grade ferro-silicon can be manufactured in the blast furnace, but only with a very high fuel consumption. Inasmuch as ferro-manganese is one of the most common alloys made in the blast-furnace, a study

was made of this process with an idea of predicting the effect to be expected with a higher oxygen blast.

To outward appearances, the blast-furnace process for the manufacture of ferro-manganese is practically the same as the blast-furnace smelting of iron. However, on closer examination we see that there are marked differences. In the first place, the coke consumption per ton of ferro-manganese is about three times that of pig iron, while the heat of reduction of manganese is very little more than that of iron. The percentage recovery in the ferro-manganese process is much less than in that of iron. Inasmuch as oxides are being reduced in both processes, charged in the same manner, and heated by the same means there must be some condition within the furnace itself which explains the great difference in economy. Considering the smelting of iron for a moment; we know that the iron charged as an oxide through the top of the furnace is rapidly reduced to metallic sponge by the ascending gases, so that it reaches the zone of high-temperature heat in the metallic state, and its only requirement in the nature of high-temperature heat is the latent heat of fusion together with sufficient heat to liquify the slag and reduce a small amount of silicon phosphorus and manganese. Considering ferro-manganese; we know that MnO_2 is reduced only at very high temperatures in the presence of solid carbon, it therefore follows that no chemical change is made in the MnO_2 during its passage down the shaft. The small amount of accompanying Fe_2O_3 is reduced here, but the major portion of the reduction accomplished in this process, that of manganese, is done in the hearth and bosh section by heat available above the critical temperature. And it necessarily follows that as we increase the requirements of heat available above the critical temperature we increase materially the fuel consumption of the furnace. Now with reference to the critical temperature this value is higher in the manganese practice than that of the pig-iron furnace, so we have less heat available above this temperature per pound of coke.

It is not my intention to burden you with the long and tedious calculations which were necessary for this study, and which are published in the bureau publication. Sufficient being that from the figures prepared it was concluded that taking the practice studied, a blast containing 26.3 per cent O_2 by weight promises an increase in production of 75.8 per cent accompanied by an 18.7 per cent reduction in cost.

It is believed that corresponding economics will be accomplished in the manufacture of other ferro-alloys. Our inability to secure the necessary data and thermal values has prevented our making individual studies of the various processes. However, they are so similar in principle to that of manganese, we can safely state that great economics may be expected if we increase the oxygen in the blast. And further, that many alloys which can now be produced only in the electric furnace, will by the use of oxygen be made in a modified type of coke blast furnace.

DISCUSSION

W. D. Brown: I was very much interested when the committee first made its report on the use of oxygen in metallurgical operations and have especially studied its use in the blast furnace.

I have made some calculations on the excess heat per lb. of coke burnt at the tuyers with hot air blast, with hot oxygenated blast and with cold oxygenated blast. What the operator is most concerned with, perhaps, is the amount of coke used. The coke burnt before the tuyeres per lb. of iron for any condition is the excess heat necessary per lb. of iron divided by the excess heat produced per lb. of coke. The calculations showed saving in coke consumption but also showed that the coke for 30 per cent by volume oxygenated cold blast was more than with air blast at 1100 deg. F., also that the coke necessary with 40 per cent oxygenated cold blast was more than with 30 per cent oxgenated blast at 1100 deg. F.

A study was then made to find how much oxygen was necessary in cold blast to obtain the same slag temperature and same coke consumption as with hot air blast at various temperatures. The excess heat per lb. of coke is the sum of the sensible heat of the blast and the sensible heat and heat of combustion of the coke, minus the heat in the products of combustion at the temperature of the slag — about 2740 deg. F. In this comparison between hot air blast and cold oxygenated blast, the sensible and chemical heat of the coke and the sensible heat of the carbon monoxide are the same for each and these are not counted.

There remains then for comparison, the heat brought in by the oxygen and the nitrogen of the blast and the heat carried out of the bosh by the nitrogen.

These are calculated per cu. ft. of oxygen:		B.T.U.
Heat in 1 cu. ft. oxygen at 1100 deg. F. =		21.88
Heat in 1 cu. ft. nitrogen is the same		
Nitrogen in air is 3.78 times the oxygen		
Heat in 3.78 cu. ft. nitrogen =		82.71
Heat brought in by air containing 1 cu. ft. oxygen =		104.59
At 2740 deg.		
Heat in 1 cu. ft. nitrogen is 58.54 Btu.		
Heat in 3.78 cu. ft. =		221.28
Excess heat taken out by nitrogen over that brought in by air =		116.69
Cold oxygenated blast:		
Heat in 1 cu. ft. oxygen =		1.33
Nitrogen may take out that much more or a total of		118.02
As above, heat in 1 cu. ft. nitrogen at 2740 deg. =	58.54	
And heat in 1 cu. ft. nitrogen at 70 deg. =	—1.33	
Excess heat taken out by 1 cu. ft. nitrogen in cold blast =		57.21
Cu. ft. nitrogen allowable for 1 cu. ft. oxygen — 118.02 ÷ 57.21 = 2.063		
Percentage of oxygen — 1 ÷ 3.063 = 32.6 per cent.		

In other words, cold oxygenated blast with 32.6 per cent by volume of oxygen gives the same excess heat, the same slag temperature and the same coke consumption as does hot air blast at 1100 deg.

Similarily, calculations have been made to find the amount of oxygen required in cold blast to equal air blast at 780 deg. F., 500 deg. F., and 1400 deg. F.

Results are given in the following table. The oxygen has also been calculated as per cent of added oxygen based on total oxygen and as the fraction of a lb. of oxygen per lb. of iron, based on 2000 lbs. coke consumption.

TABLE

Oxygen in cold oxygenated blast to equal air blast at various temperatures.

Temperature of air blast — 0 deg. F.	500	780	1100	1400
Oxygen in cold blast to equal above (by volume)	24.5	27.7	32.6	39.5
Oxygen added in per cent of total oxygen	18.8	31.0	45.4	59.5
Oxygen added per lb. of iron (2000 lbs. coke)	.154	.255	.372	.488

Cost comparison of hot air blast with cold oxygenated blast, with sufficient oxygen to equal hot air blast.

	780°	1100°
Saving on oxygenated cold blast at		
Heat required to heat blast in million Btu. per ton iron at 75 per cent stove efficiency	2.1	4.0
Cost of this gas at $.15 per million Btu	$.32	$.60
Mr. Davis has estimated cost of stoves at	.35	.35
Total savings on cold oxygenated blast	.67	.95
Cost of oxygen at $3.00 per ton	.77	1.12
Excess cost of oxygenated cold blast per ton iron	.10	.17

A graph has been constructed from the table and is included.

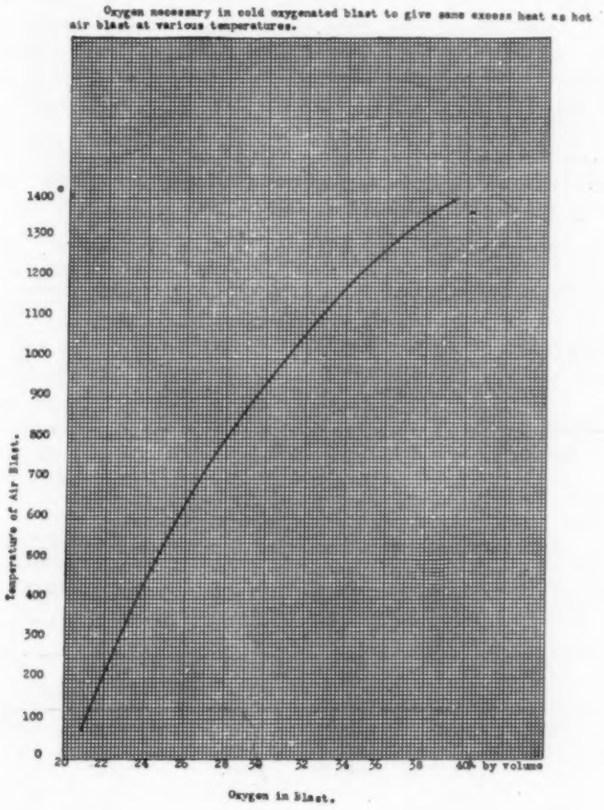

FIG. 1.

But great savings in coke and increase of iron production may be obtained by use of hot oxygenated blast. I have made calculations similar to those outlined comparing 25 per cent oxygen blast with air blast, both at 1100 deg. F., and show a saving of 30 per cent in coke consumption and an increase of 50 per cent in iron production, considering the same amount of coke burnt before tuyeres per day. The oxygen used would be .114 ton per ton of iron at a cost of $.34 per ton. The top gases in this instance would be 27.9 per cent CO_2, 20.4 per cent CO, 51.7 per cent N_2 with a ratio of CO_2 to CO_2 + CO of .572. This is higher than our usual practice but this gas would reduce iron oxide at a temperature below 750 deg. F. Even a smaller percentage than 25 per cent by volume of oxygen would show remarkable improvements.

As the amount of carbon burnt before the tuyeres per lb. of iron is lessened, due to oxygenated blast, the ratio of CO_2 to the sum of CO_2 and CO increases, the amount of CO_2 per lb. of iron being fairly constant. As a result the point may be reached where the gas, due to the high ratio, will not reduce the oxide of iron at the top of the furnace even at the lower temperature, this reduction being a factor of the ratio of CO_2 to CO_2 + CO and of the temperature.

As I see it, the use of oxygen in the manufacture of ferro alloys in the blast furnace is not limited by that condition since the reduction of the alloy is by solid carbon in the hearth. Increase in oxygen per lb. of coke, would cause decrease in the amount of coke burnt before the tuyeres per lb. of alloy, the carbon used for the reduction of the alloy and its impregnation being constant.

The use of oxygenated blast in the basic Bessemer process has great possibilities. I am of the opinion that more is to be expected of this method or of a duplex method of basic Bessemer and electric furnace than in attempting to bubble oxygen through the bath of the open hearth.

A. G. Witting: The perspective opened by Mr. Davis' paper on "Oxygen Enrichment" is indeed very pleasing to those who are directly interested in the fight for higher fuel efficiency. The possibility of production of oxygen on a large scale at a low price will mean the greatest step forward in the evolution of the production of iron and steel, not to say a complete revolution.

While Mr. Davis has covered a wide field in his paper, as well as in the study presented in the Serial No. 2502 issued by the Bureau of Mines, one would feel tempted to try to speculate even farther, for example about the application of oxygenated producer gas and oxygen to the direct process for the reduction of iron ore to metallic iron at a low temperature by the action of such gas on the ore, afterwards melting the iron sponge by burning the partly spent gas with oxygen, using a certain amount of the ensuing waste gases — which besides small quantities of nitrogen and oxygen will hold equal parts of CO_2 and H_2O —instead of steam for regulation of the temperature in the producer.

There is, however, more than sufficient food for thought for one sitting in the problem of the application of oxygen to blast furnaces and open hearths, including gas producers, as it is presented in Mr. Davis' paper. As a matter of fact, there is so much of interest in it that, though I have had a copy of the same and the serial No. 2502 for some days, I have not been able yet properly to study it. I will therefore content myself to a few remarks about the use of oxygen instead of air in gas producers, because I have previously had occasion to consider this question. As any practical test so far to my knowledge has not been attempted, the discussion must needs be altogether theoretical, and everybody is entitled to his own opinion. But it is better to be over careful in drawing conclusions than too optimistic, and, above all, the calculations must be able to stand a close scrutiny.

While I might appear in my discussion as trying rather severely to criticise the data presented by Mr.

Davis on pages 23 and 34 in above mentioned serial, I don't want in any respect to be classed as a fault finder of these extremely interesting and valuable papers. My criticism probably does not seriously affect the ultimate conclusions that may be drawn, but it is to deplore that Mr. Davis has selected as a basis for his calculations certain data which will not stand scrutiny. With all due respect for the eminent work by Professor Richards and, otherwise, for his book "Metallurgical Calculations", the example of producer gas which here is in question is a very unfortunate one. Professor Richards starts with a gas, the result of a test which for one reason or other has been given the stamp of authority — it is for example quoted in Kent's Handbook. The gas was supposedly produced from the best quality of Illinois coal, we might say a super quality, which gas has a heat value of no less than 221 Btu. per cu. ft. gross (or 209.4 Btu. low value). Such gas has never been produced outside a laboratory or when the producer was operated as in a laboratory. The test was run many years ago, and if I am not mistaken the gasification was less than 400 lbs. an hour with a 40 in. deep fuel bed; nowadays a producer is supposed to gasify up to 2000 lbs. per hour and fuel beds over 20 in. thick are seldom found. But even so, I do not think it possible to produce any such gas from Illinois coal; that is to say, a gas containing the right proportions between the distillation products of the volatile and the gasification products from the fixed carbon. As a rule, when a gas sample is taken the operator, anxious to show his best, dumps coal so that extra volatile is developed and enters into the gas out of its correct proportion. In our studies of gas producers we have often obtained samples running over 200 Btu., yes as high as 509 Btu., which means about 100 per cent distillation products with no gasification products. My contention is that a perfect gas produced from the best Illinois coal will not show over 150 Btu. (low value) and I am sure anyone who has had to do with the operation of producers using this kind of coal will agree that a gas averaging 130 Btu. (low value) is excellent.

With regard to the composition of this gas I would particularly like to call attention to the ratio between C_2H_4 and CH_4 which is practically 1:1. At the laboratory tests carried out once by the Bureau of Mines (Bulletin No. 1) it was at best 1:4. In normal producer gas, where secondary pyrogenetic reactions occur it will never exceed 1:3 ($CH_4 = C_2H_4 + H_2$). But that is not all. It is obviously assumed that all the hydrogen shown in the ultimate analysis enters the fixed gas; consequently the coal has no hygroscopic water — a very unusual condition. Furthermore, the oxygen in the gas from one pound of coal will figure out to be 0.7861 lb. According to the data on page 24 there should be in the same volume of gas 0.5850 lb. oxygen from air and 0.3144 lb. from the decomposed steam, while the coal itself contained 0.11 lb., a total of 1.0094 lb. oxygen. The question is what has become of the difference or 0.2233 lb. As there was nothing to make it disappear, we must draw the conclusion that 0.7432 lb. nitrogen, or 37 per cent of the total which in an air mixture accompanies 0.2233 lb. oxygen has not been derived from the air but from another mysterious source.

Having thus torn down the foundation on which the calculations are based, it might be superfluous to point out that the presence of tarry vapors in the gas has been entirely neglected and that it has been assumed that all the gasified parts of the coal appear in the permanent gases according to the analysis, something that never is the case. Furthermore, the temperature at the top of the producer is given as 1900 deg. F., which is not possible unless something is decidedly wrong with the operation. The temperature should not exceed 1200 deg. F. if the best quality of gas is produced.

The heat value of the coal is given as being 13338 Btu. per lb. The gas volume with oxygen is stated to be 32.14 cu. ft. per lb. coal. Its low heat value is 378.9 and the calorific power of the gas consequently 12178 Btu. But the gas carries a sensible heat (at 1900 deg. F.) of 1518 Btu. Furthermore, even if we assume that 100 per cent of the steam entered with the blast is decomposed, there remain the moisture in the coal which following the gas and heated to 1900 deg. F. has a sensible heat of 62 Btu. Consequently the gas at the top of the producer has a total heat value of 13758 Btu. The process of converting one lb. of coal with the assistance of oxygen has consequently been accomplished with an efficiency in excess of 100 per cent.

Now, as an illustration of what, to my belief, is the very best results that can be obtained from a good quality of Indiana coal not unlike, if not quite as good, as the one used by Mr. Davis — if oxygen is employed for the gasification, I will present some calculations which, I hope, better will stand a close examination except that some assumptions (intentionally made) might be assailed as too optimistic.

Proximate Analysis of Coal (Natural State)		Ultimate Analysis of Coal (Natural State)	
Volatile matter	35.51%	Carbon	67.91%
Fixed carbon.....	48.28	Hydrogen	4.83
Moisture	6.80	Oxygen	8.48
Ash	9.41	Nitrogen	2.57
	100.00		

Note: 5.09 per cent oxygen, 0.895 hydrogen and 1.213 nitrogen exist in the coal (or are produced at the distillation) as H_2O and H_3N, inert condensible gases and counted as moisture.

From one lb. of this coal 59.52 cu. ft. of fixed gas are produced, out of which 5.12 cu. ft. are products of distillation and 54.4 cu. ft. products of gasification.

ANALYSIS OF GAS

Products of Distillation		Products of Gasification		Total	
CO_2	1.95%	CO_2	8.57%	CO_2	8.0%
C_2H_4	4.65			C_2H_4	0.4
CO	11.78	CO	21.87	CO	21.0
H_2	43.18	H_2	7.20	H_2	10.3
CH_4	34.85			CH_4	3.0
N_2	3.59	N_2	62.36	N_2	57.3
	100.00		100.00		100.0
Btu.	545.29	Btu.	90.87	Btu.	130.0
		Carbon converted to			
		CO_2	28%		
		CO	72		

This gas was produced by a steam air blast consisting of 0.4 lbs. steam and 42.88 cu. ft. air. The total amount of moisture carried by this gas amounts to 8.80 cu. ft. Furthermore, there is (assuming that 50 per cent of the tarry vapors are dissociated into fixed gas and that 50 per cent follow the gas as condensable hydro-carbon) 0.15 cu. ft. of tarry vapors with a heat value of 6070 Btu. per cu. ft.

The composition of the gas as carried away from the producer is:

	Cu. Ft.	Btu. per Cu. Ft.	Btu.
Products of distillation..	5.12	at 545.29	= 2794.42
Products of gasification..	54.40	at 90.87	= 4943.43
Total fixed gas.....	59.52	at 130.00	= 7737.85
Tarry vapors	0.15	at 6070.00	= 904.74
Moisture	8.80	.....	.....
Total gas	68.47	at 126.22	= 8642.59

With a temperature of 1200 deg. F. at the top of the producer the gas has a sensible heat of 1829.92 Btu., its specific heat at that temperature being 0.02227 per cu. ft.

The total volume of this gas produced from one lb. of Illinois coal with steam-air blast has a calorific power of 10,472.51 Btu.

Assuming that the gas was produced by means of oxygen (which carries 5 per cent nitrogen), that the heat absorbed by the nitrogen in the air is utilized to dissociate additional steam and that due to more concentrated reactions 85 per cent of the fixed carbon is gasified to CO (instead of 72 per cent) the result would be:

> Per lb. coal 33.92 cu. ft. or 2.5025 lbs. nitrogen from the air heated to 1200 deg. F. (specific heat per lb. = 0.25476) absorb 765.04 Btu. one lb. steam requires (Davis, page 34) 5740 Btu. Accordingly 0.13328 lb. steam can be dissociated by this heat producing 0.01481 lb. hydrogen.

There can not be any change as to the volume or composition of the products of distillation from the volatile matter, nor is it assumed that the tarry vapors will be affected differently. The volume of water vapor following the gas will be less to the extent of the moisture in the air, it being assumed that the oxygen is perfectly free from moisture.

From one lb. of the coal 28.79 cu. ft. of fixed gas will be produced, of which 5.12 cu. ft. are products of distillation and 23.67 cu. ft. products of gasification.

ANALYSIS OF GAS

Products of Distillation		Products of Gasification		Total	
CO_2	1.95%	CO_2	10.45%	CO_2	8.9%
C_2H_4	4.65			C_2H_4	0.8
CO	11.78	CO	59.56	CO	51.1
H_2	43.18	H_2	28.35	H_2	31.0
CH_4	34.85			CH_4	6.2
N_2	3.59	N_2	1.64	N_2	2.0
	100.00		100.00		100.0
	Btu.		Btu.		Btu.
	545.29		271-80		320.5 low value 343.0 high value

The composition of the gas and its heat value will be:

	Cu. Ft.	Btu.	Btu.
Products of distillation..	5.12	at 545.29	= 2794.42
Products of gasification..	23.67	at 271.80	= 6433.56
Total fixed gas.....	28.79	at 320.50	= 9227.98
Tarry vapors	0.15	at 6070.00	= 904.74
Moisture	8.03	.....	.....
Total gas	36.97	at 274.08	= 10132.72

With a temperature of 1200 deg. F. at the top of the producer the gas has a specific heat per cu. ft. of 0.02333 and a sensible heat of 1034.86 Btu.

The total volume of gas produced from one lb. of Illinois coal with oxygen has a calorific power of 11167.57 Btu.

The increased heat value of the gas produced from one lb. of coal is very small and of course more could not be expected. The gain that will pay for the expense of the oxygen will come from the greater efficiency obtained by higher degree of radiation, due to a higher flame temperature and also to the fact that with the same amount of tarry vapors following the gas there will be about 20 per cent more dissociated carbon particles per cu. ft. gas air mixture in the furnace.

I will not try to speculate on the results that might be obtained or on the different methods and designs of producer and furnace that might be necessary, but will, in conclusion, content myself with pointing out some of the differences.

GAS PRODUCED FROM ONE LB. OF COAL

	With Air	With Oxygen
Lbs. steam used.....	0.40	0.69
Cu. ft. steam (at standard).....	8.43	14.59
Cu. ft. dry blast.....	42.88	6.84
Total blast	51.31	21.43
Ratio steam to blast.....	1:5.09	1:0.47
Cu. ft. combustible gas.....	59.67	28.94
Total cu. ft. gas produced.....	68.47	36.97
Btu. per cu. ft. (low value).....	126.2	274.1
Total calorific power.....	8643	10133
Sensible heat at 1200 deg. F.....	1830	1035
Total heat capacity.....	10473	11168
Cu. ft. air needed for combustion	92.12	99.99
Ratio gas to air.....	1:1.345	1:2.704

H. C. Siebert: I would like to ask Mr. Davis, who today is manufacturing oxygen at $3 per ton, or let us say even $5 per ton? I am not speaking of oxygen in bottles, I am referring when I speak of oxygen at that price to large quantities such as we must have for application to the iron blast furnace.

F. W. Davis: In answer to that question as to who is manufacturing oxygen for $3 a ton for blast furnace purposes; there is not enough oxygen manufactured in this country today to supply one blast furnace. We have found in our investigation, however, that it is possible to manufacture plants of this nature. I should like to quote in this connection, an extract from an article by Mr. L. Marchis, published in Metallurgical and Chemical Engineering of February 15, 1916, in which he describes the counter flow method of G. Claude for the preparation of pure oxygen:

> "The delivery of this apparatus is approximately 35 3/10 cubic feet of pure oxygen per effective hp. hr. for the size producing 1765.7 cubic feet per hour; 42 4/10 cubic feet for the sizes producing from 3,530 to 7,063 cubic feet per hour; 53 cubic feet for the sizes producing 35,300 cubic feet per hour, operating at pressures of 10 atmospheres at the most. For these latter, aside from the motive power, the cost (labor and fixed charges included) will not exceed five-thousandths of a cent per cubic foot, with the motive power available at the neighborhood of furnaces and water falls, the total cost of oxygen will result at about one-hundredth of a cent per cubic foot or $2.62 per ton of 2,000 lbs."

Here is a statement quoting Claude, who is probably the best informed man on this subject in the world. It was made some years before this committee started to function, so that it is apparent that the Bureau of Mines is not alone in considering and pre-

dicting cheap oxygen. As I said, however, it must be made in large units at the point of application for this price to hold true.

With reference to the gas producer study, it is unfortunate that we were obliged to take a problem from a text book. At the time this report was under preparation we had nothing available on actual gas producer practice which were sufficient in detail to permit of such a study being made. With reference to the high efficiency on that gas producer, was not the figure quoted, obtained from the analysis of the coal rather than from Richard's calorimetric value?

H. C. Siebert: Only one more question in connection with the cheapness of oxygen — from information that we have and it is that information which led me to ask the question of Mr. Davis, there seems to be a very remote probability of oxygen being manufactured on any large scale at any such price.

Dr. J. S. Unger: Without attempting to deal with the mathematical side of the question, there are a few pertinent things that have occurred to me. For the last several years there has been a great deal written about cheap oxygen. It was publicly announced in New York City last year that oxygen could be furnished in quantity at a price not to exceed $3 a ton.

A very excellent article on Oxygen-enriched air is found in the "Iron Age" issue of March 20, page 849, by W. S. Landis, who deals with the situation, and it is really worth reading.

I know of five cases in which attempts have been made to use oxygen metallurgically. Three of them were made abroad, two of them at home. With the exception of one case, the apparatus and equipment used for the tests was destroyed in a few minutes.

Rather than theorize and cover page after page with the use of pure or almost pure oxygen in iron metallurgy, it would be more convincing to have from 10 pounds to a ton of pig iron on exhibition that was made with oxygen of a purity of say at least ninety-five per cent. If one must use oxygen of say a lower degree of purity than say 95 per cent, some of the commercially valuable advantages disappear. Slightly enriched air will have little, if any, value as it will require almost as much equipment as is required to operate a blast furnace today.

Oxygen may be furnished in large quantities at $3 a ton. This has been claimed for more than a year. I want to say that the present price of industrial oxygen which is about 50 times of that which is quoted, has not fallen in cost during this time. We pay as much for it as we used to.

I know of one experiment in which an attempt was made to reduce iron ore in a small experimental blast furnace using oxygen. I saw the iron after it had been made. It was about the size of one's two fists. As a matter of fact, there was very little if any of the apparatus remaining after the experiment was over, which was complete in about one minute.

To give you an idea of what a mixture of coke and oxygen will do, we know that there are permissible explosives on the market made up of powdered carbon and liquid oxygen. They act sufficiently quickly to be used as an explosive. It is my idea that there is not much opportunity for chemical control in an operation that is as speedy as that.

I also know that in the reduction in this particular experimental furnace there was some pig iron present, but the regulus contained everything from unreduced ore to high carbon iron on analysis.

We found that the reaction had been so rapid that long before some of the ore had an opportunity to be reduced, it was melted on the surface and beautifully glazed. When we broke away the particles of glazed ore we found unreduced ore at the center which had never been affected by the carbon and oxygen.

I know of two cases in which oxygen has been used in an open hearth furnace for the enrichment of the air. In one case, I am unable to secure any data. In another case where oxygen was used in amounts up to approximately 8 per cent for a short time, they did not secure any advantage from the enriched air that was put into the furnace.

They could not make extensive experiments as the oxygen supply was limited by the number of oxygen bottles they could connect up and turn into the air supply.

As to the use of oxygen in the Bessemer converter. You chemists take drillings and heat them to a nice bright red and do not have any trouble burning these hot but not molten drillings in the tube, every time you make a carbon combustion. Assuming that this material was molten and you were bubbling oxygen through the molten mass, do you think that you could introduce a type of selective combustion in which you would burn out the silicon, manganese and carbon without burning out the iron, particularly when the molten material burns with almost explosive violence?

I believe if you turned oxygen into the tuyeres of a Bessemer converter, in a very short time you would have a mixture of oxide of iron and metallic iron that it would be almost impossible to separate.

I did refer to the question of chemical control. You may be able to control your temperatures by a little more heat in the hearth of a blast furnace if you had the time, but when you attempt close chemical control in an operation that is over in perhaps two or three seconds, I don't think you have very much opportunity to do any controlling.

It is stated that by the use of oxygen we will use poorer fuel than before, ores containing more gangue than in the past, but we must not forget that the higher ash of the coke, and the higher gangue in the ore means additional slag-forming material which must be melted. We know in certain localities where they operate blast furnaces with ore of a low iron content, they use considerably more coke than with normal ore and normal coke.

F. W. Davis: I would like to have just a moment.

Dr. Unger suggested that experiments should be made. That is exactly what we desire.

The Bureau of Mines has made a study of possible effects to be expected from the application of oxygen to metallurgical processes, to use as a guide in an experimental campaign which will be undertaken, we hope in the near future. The report issued on this study is an indication only, as to the direction to which we may look for improvement and is not intended to even approximate the extent of these improvements.

So far as experimental furnaces are concerned, we have an experimental furnace at the Bureau Station in Minneapolis which I would like to invite you gentlemen to inspect. This furnace makes three tons of

pig iron a day, the product may be cast in regular pigs, and the analysis is quite uniform. We feel that in this furnace we have a workable unit in which to introduce oxygen blast or in faet to study any other problem relating to the metallurgy of iron smelting.

I, too, have heard of some of the disastrous results of at least one of the oxygen experiments. I have in mind one which was made in this country. This experiment was made on a small size furnace which had never been run with ordinary air. The experiment was started, I believe, with a 60 per cent oxygen blast. Had results been obtained from this furnace what would they have meant? With what could we have compared them? The equipment was not standardized and any results obtained would have been interesting, I'll grant, but as a basis for comparison of two processes would have been absolutely valueless. To start on a campaign of this nature one should take a small furnace, run it in the usual manner with ordinary air until the furnace is standardized. The next step should be to increase the oxygen of the blast by a small amount, say one per cent; run with this slight enrichment until the operation is balanced. Now we may observe any changes which may have occurred and can gradually increase our oxygen until we reach our limitations. We do not wish to start with 100 per cent oxygen and work down.

Of course, we must admit with Dr. Unger that nature made the air, but on the other hand, nature did not make the blast furnace. The blast furnace is the result of efforts to more economically make pig iron, when using a medium of combustion which contains 77 per cent by weight of inert matter. It stands to reason therefore that the modern blast furnace will not take 100 per cent oxygen and make pig iron economically. I should however hestitate to admit that because this blast furnace, which is built up to accomodate combustion with air, is the best that can possibly be made and that if more active material for combustion is available it is not possible to design a blast furnace which will take advantage of the purer material.

Regarding the Bessemer converter, I do not know exactly what takes place when air first comes in contact with the molten metal, and I doubt if any one can be positive on this point. I do not believe, however, that air in itself performs selective oxidation. If natural air is passed through molten pig iron, you can't convince me that just because it is natural air it will not react with the iron present, but will only oxidize the impurities, because they are undesirable and because the operator wants them removed.

My idea of the actual reactions in the Bessemer converted is as follows:

The oxygen in the blast unites with the first atom of metal or metalloid which it meets, in a large majority of cases I should judge this to be iron. The iron oxide so produced circulates in the bath and is reduced by other materials which have a greater affinity for oxygen than has iron. I can see no reason to infer that a blast containing less nitrogen than air will disturb this cycle. For this reason I do not fear that by increasing the oxygen content of the blast by say 10 per cent, we are going to burn nothing but iron.

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*The Ljungstrom Air Preheater**

By B. G. BROLINSON, M. E.†

THE greatest source of loss in connection with steam boiler operation is the quantity of heat carried away by the flue gases. The days have long passed in which a high exit temperature of the gases was tolerated for the sake of producing natural draught, and in order to obtain higher efficiencies, economizers have frequently been employed to utilize as far as possible the heat which cannot be extracted from the gases by the boiler proper.

The close regulation of excess air supply to the fires which is rendered possible by the use of CO_2 recorders has had its natural effect in increasing the temperature of the exit gases, and this again has called attention to the amount of recoverable heat which these gases contain.

In modern power plants there has also been a tendency towards running the boilers at a comparatively high rating which of course has the effect of increasing the temperature of the flue gases, or in other words of increasing the stack loss. As an alternative to the use of economizers, it has often been proposed to use the heat of the waste gases to raise the temperature of the air supplied to the boiler. The practical benefits of doing this are considerably greater than one would deduce from simple arithmetical calculations. The advantage does not stop with the mere return of a certain amount of heat units per hour to the furnace. The hotter air supply also results in a livelier combustion which naturally increases the furnace temperature and consequently also increases the rate of radient heat transmission to the boiler in a much greater ratio than the heat recovery, the absorption increasing with the fourth power of the absolute furnace temperature.

Consequently the process of combustion and the transmission of heat to the boiler take place under very favorable conditions, therefore it is also possible to successfully burn low grade fuel containing a great percentage of ash and moisture.

It should also be noted that preheating of the combustion air leaves the possibility open for additional savings that can be made by heating the feed water in a rational manner, for instance by suitable bleeding of steam from the steam motor resulting in a saving of fuel from 4 to 8 per cent, and by utilizing the exhaust steam from auxiliaries or steam that has been applied to various manufacturing processes in boilers, dryers, evaporators, et cetera.

There are two ways by which it has generally been attempted to raise the temperature of air for combustion. In steel works' furnaces a common practice is to pass the fresh air and the flue gases alternately through a

*Paper read before the Association of Iron and Steel Electrical Engineers, Fuel Saving Conference.

†Resident Engineer, A. B. Ljungstroms Angturbin, Stockholm. Chief Engineer, James Howden & Co. of America, Inc., Wellsville, N. Y.

regenerating chamber so that the incoming air picks up heat from the brick work previously raised to a high temperature from the passage of flue gases.

For boiler furnaces the flue gas temperature is not sufficiently high to make this plan practicable, quite apart from the difficulty of carrying it out. Hence, when regeneration has been applied to steam boiler plants it has

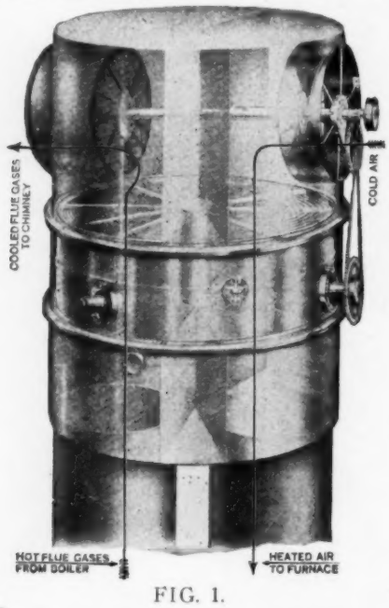

FIG. 1.

been customary to transmit the heat from the waste gases to the incoming air through metallic surfaces separating the air passages from the flues. Heat transmission under such circumstances is not very effective as the temperature difference is not great and the surfaces of the heat-

FIG. 2.

ing device are liable to become covered with a layer of soot or tarry matter which acts as a non-conductor.

Method of Heat Transference.

As will be seen from Fig. 1, the Air Preheater invented by Mr. Fredrik Ljungstrom, chief engineer of the Ljungstrom Steam Turbine Company, Sweden, is unique in that it embodies neither of the principles referred to above, but carries heat continually in a mechanical way from the flue gases to the incoming air. It will further be observed that the apparatus is self-contained, compact in design, simple in operation, and permits of ready application either to existing boiler plants or new installations.

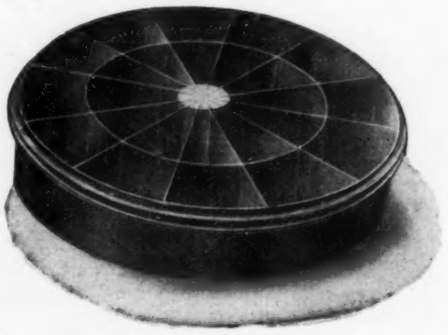

FIG. 3.

Referring to Fig. 1; fresh air is drawn by a fan into the upper portion of the casing which is divided into two parts by a vertical partition. The air is confined to one side of the partition and passes downwards

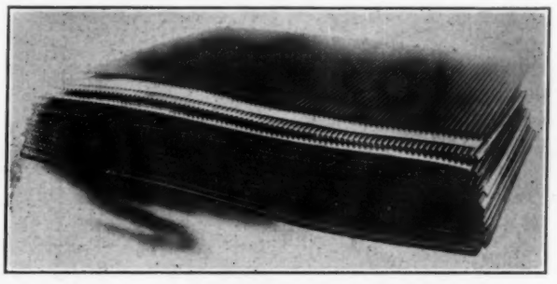

FIG. 4.

through a porous cylindrical drum or rotor to a similar semi-circular chamber in the lower part of the housing. The flue gases from the boiler traverse the apparatus in a reverse way, entering the lower semi-circular chamber and passing upwards through the rotor to the

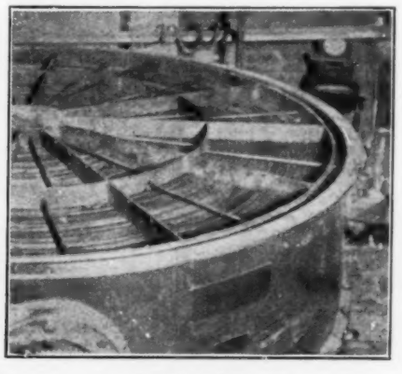

FIG. 5.

upper chamber, whence they are exhausted and impelled to the stack by another fan.

The rotor is kept in a state of continual slow rotation so that the part heated by the flue gases is continually passing to the other side of the device and gives up its heat to the cold air sweeping through it. Similarly, of course, the cool part of the rotor is continually returning to be reheated by the flue gases.

It will be observed that there is no transference of heat through metal in the process. A deposit of soot or tarry matter does not therefore have any very serious effect on the efficiency of the apparatus, which moreover may be cleaned in a few moments by means of a steam jet, without interference with the operation of the heater.

FIG. 6

Constructional Detail.

Fig. 2 gives external view of the Preheater showing the air fan and the driving arrangement of the rotor.

Fig. 3 shows the construction of the rotor. The frame work is built up from sheet steel, the parts being joined by means of electrical welding. In each section of the rotor the heating elements are placed concentrically, resting on radially fastened steel bars and held down by means of round bars on the top. On the outside of the rotor, a heavy steel ring is fastened, against which the carrying and guide rollers are working. The heating elements consist of specially corrugated plates, alternating with plain partition plates, as shown in Fig. 4, thus forming when assembled a great number of passages resembling a honey-comb structure.

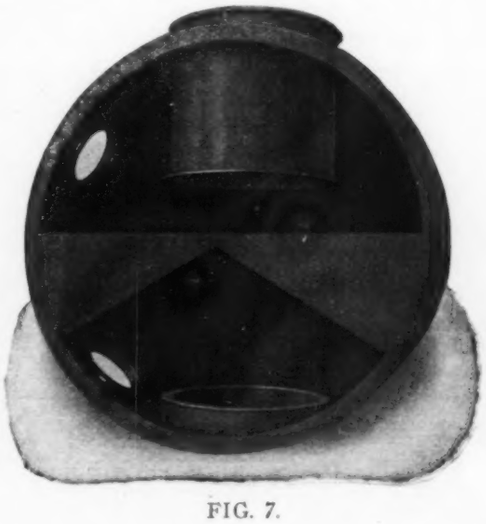

FIG. 7.

It will be appreciated that this design allows a very large heating surface to be provided in a heater of comparatively small dimensions, and with very little obstruction to the passage of the gases and the air.

The heating surface required under varying conditions has been experimentally ascertained and is generally made from three to five times that of the boiler for which the heater is designed. This, of course, results in a most effective cooling of the flue gases and heating of the fresh air respectively.

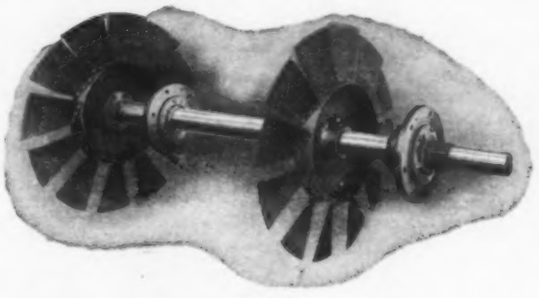

FIG. 8.

Fig. 5 shows the rotor assembled with the heating elements. It also shows the nickel tightening strips which are mounted on the radial spokes, as well as on the periphery of the rotor in order to prevent leakage.

Fig. 6 shows the middle and the lower housing bolted together. The sector shaped partition wall can be plainly seen and also the rollers for carrying the rotor and for keeping it centered.

The soot blowing arrangement which consists of a specially constructed self-draining valve in connection with a jet pipe, is mounted on the lower housing under the rotor.

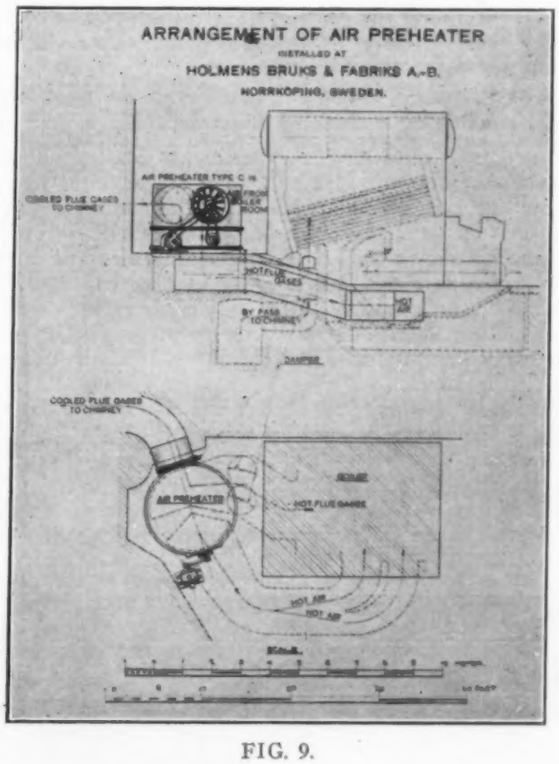

FIG. 9.

We notice that the rotor has no internal bearings or shafts exposed to hot gases but rests on externally

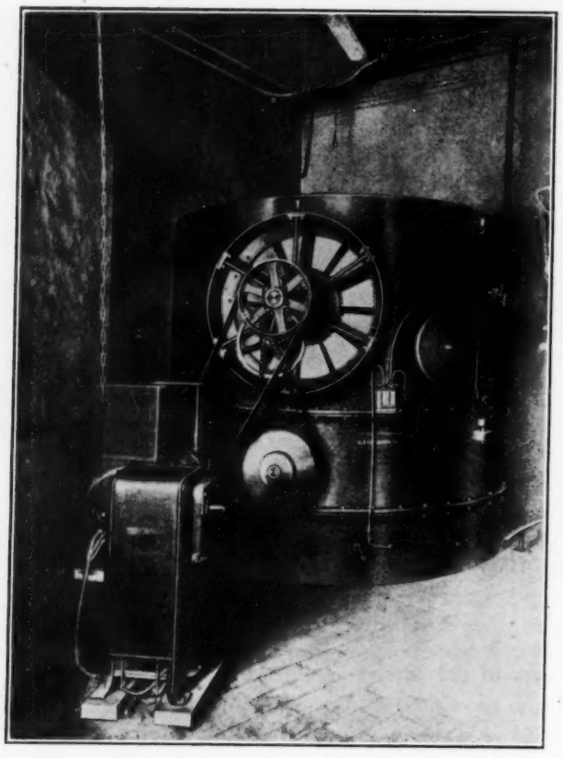

FIG. 10.

mounted carrying rollers surrounded by the fresh air and accessible from the outside.

Fig. 7 shows the upper housing with the sector shaped diaphragm and the two fan housings.

The two fans are shown in Fig. 8, mounted on a common shaft revolving on ball bearings.

A very complete series of experiments has been made on these fans in order to increase the efficiency and adapt the fans for the service required. The blades of the air fan can be set at different angles which, in conjunction with the regulation of the speed, makes it possible to give the fans a final adjustment to take care of the individual characteristics of the boiler with various kinds of fuel. On installations operating at varying load, this arrangement has proven very successful.

Air Preheater Installations.

Fig. 9 shows the general arrangement of a C-16 Air Preheater, applied to a 325 hp. boiler of the inclined water tube type equipped with chain grate stoker. In making this installation, the Preheater was placed on the floor behind the boiler and the gases were taken in from the bottom. The hot air was also taken out at

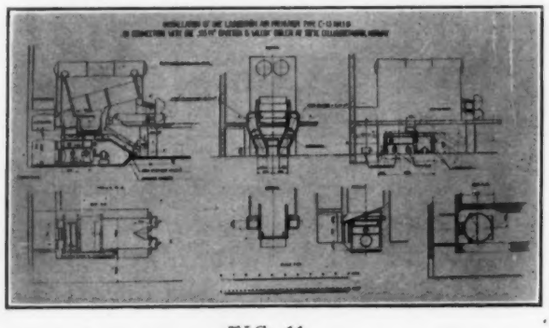

FIG. 11.

the bottom and by means of a concrete duct under the floor the air was conducted over to the furnace.

Fig. 10 is a photograph showing this installation. The fans are driven by an a.c. motor equipped with variable speed control as can be seen in the foreground. The photograph also shows the driving arrangement and a

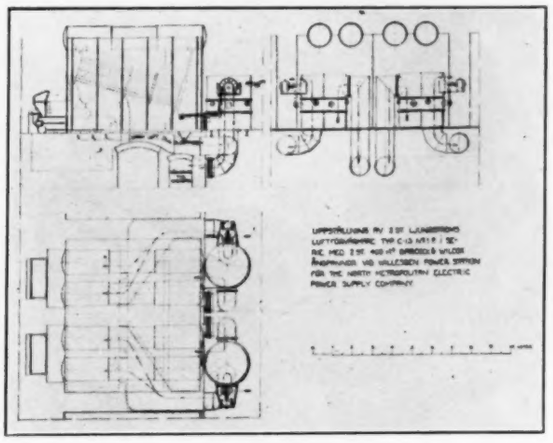

FIG. 12.

gauge for measuring the resistance through the heater. This installation has been in continuous service since December, 1922.

The comparative tests with and without the Air Preheater show a saving in fuel of about 19½ per cent due to the application of the Air Preheater. The air temperature is about 545 deg. and the furnace temperature approximately 2,462 deg. F.

Fig. 11 shows a Ljungstrom Air Preheater installed in connection with a 335 hp. B. & W. boiler at a paper mill in Norway. In this case, the Preheater was placed under the boiler. The flue gases pass straight down from the boiler to the Preheater and out through the flue, and the air is passed from the heater through a concrete duct up to the stoker, making a very simple and compact layout.

Fig. 12 shows the general arrangement of the Ljungstrom Air Preheater at the Willesden Station of the

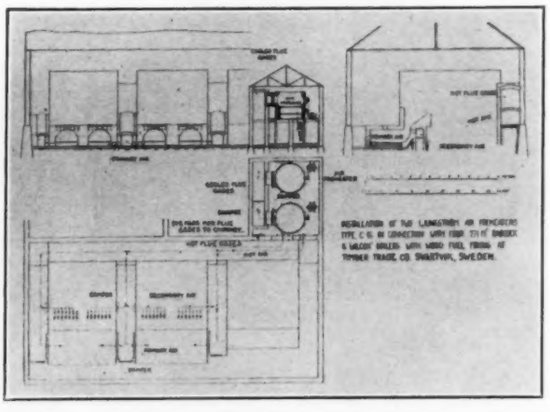

FIG. 13.

North Metropolitan Electric Power Supply Company, near London. This installation has been in service for some time and has proved very satisfactory.

During the comparative tests, an efficiency of 74.56 per cent was obtained without Air Preheater, while the efficiency was increased to 84 per cent with the Air Pre-

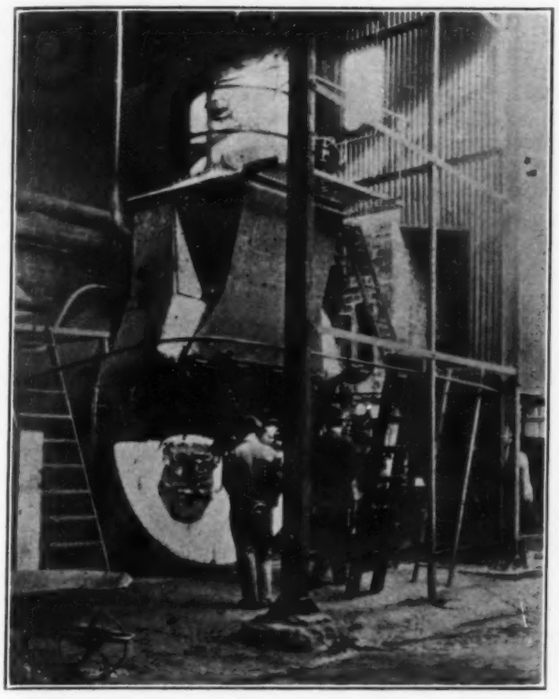

FIG. 14.

heater, based on gross calorific value of the fuel. The fuel used was a mixture of low grade coal and fine culm, having a heat value of 10470 to 10850 Btu. as fired.

Fig. 13 shows two C-16 Ljungstrom Air Preheaters installed in connection with four 275 hp. B. & W. boilers, burning wet wood refuse containing about 60 per cent moisture, at Svartvik, Sweden. The furnace is of a Dutch Oven type, and secondary air inlet was employed. This installation has proven most satisfactory, the evaporation being approximately doubled as a result of using preheated air for combustion.

Fig. 14 is a photograph of a Ljungstrom Air Preheater installed on a Scotch marine boiler at the Works of James Howden & Company, Ltd., Glasgow, Scotland.

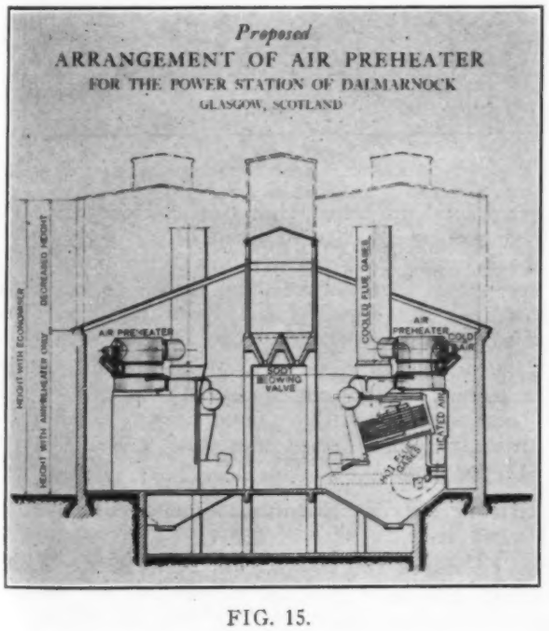

FIG. 15.

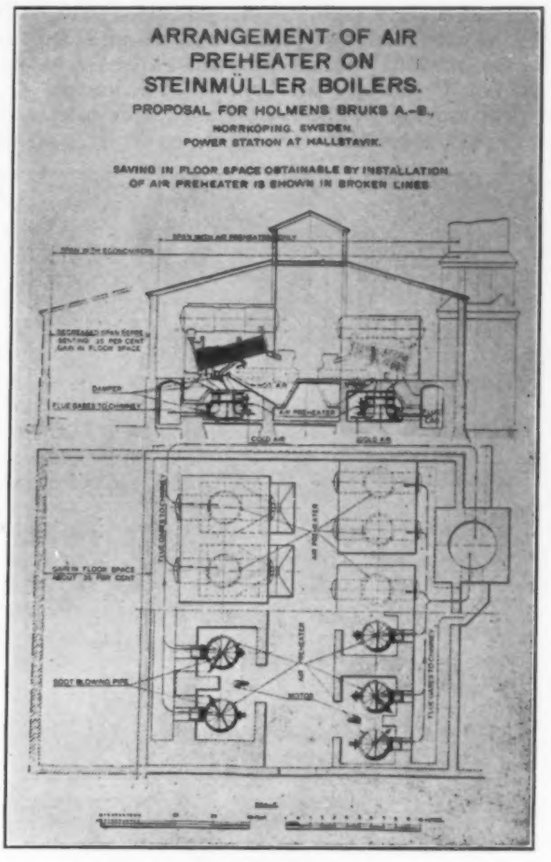
ARRANGEMENT OF AIR PREHEATER ON STEINMÜLLER BOILERS.
PROPOSAL FOR HOLMENS BRUKS A.-B.,
NORRKOPING, SWEDEN.
POWER STATION AT HALLSTAVIK.
SAVING IN FLOOR SPACE OBTAINABLE BY INSTALLATION OF AIR PREHEATER IS SHOWN IN BROKEN LINES
DAMPER
COLD AIR
SOOT BLOWING PIPE
MOTOR

FIG. 16.

The boiler is equipped for burning either coal or oil. With Scotch coal having a gross heat value of 12,300 Btu., an efficiency of 85.49 per cent was obtained. Burning Mexican oil with a heat value of 17,574 Btu., an efficiency of 87.6 per cent resulted. Later tests on the same equipment have given a maximum efficiency of 90.7 per cent.

During the test the boiler was developing about 220 per cent rating.

Fig. 15 shows a proposed arrangement of Ljungstrom Air Preheaters in the Dalmarnock Power Station of the Glasgow Corporation, Glasgow, Scotland. The boilers are of the B. & W. marine type, having 6,948

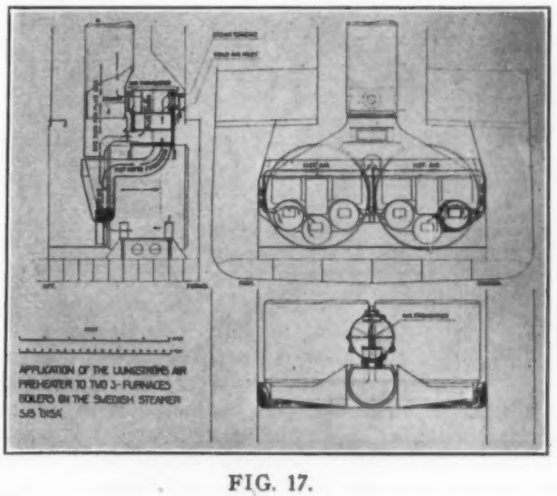

FIG. 17.

sq. ft. heating surface each, and are equipped with chain grate stokers each having a grate area of about 273 sq. ft. In this case, it would probably be most suitable to employ two Air Preheaters per boiler. The flue gas discharge is at the top of the boiler, making it most convenient to place the Preheaters above the boiler, and the

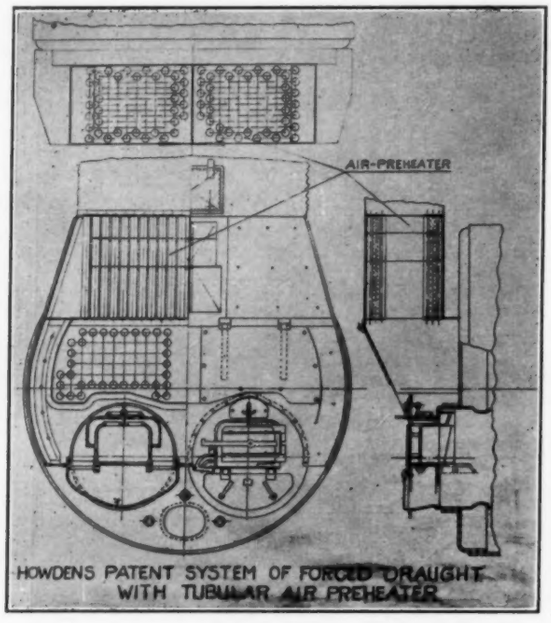

FIG. 18.

heated air could be taken down at the back of the boiler with a door through the air duct to give access to the boiler tubes. At present these boilers have economizers containing 400 tubes about 14 ft. long, 3-15/16 in. in diameter, and space for the economizers has been provided above the boilers.

The picture shows how the height of the boiler house could be decreased if the Air Preheaters were installed instead of the present economizers. In addition to the saving in height of the boiler house corresponding to the space occupied by the economizers on the second

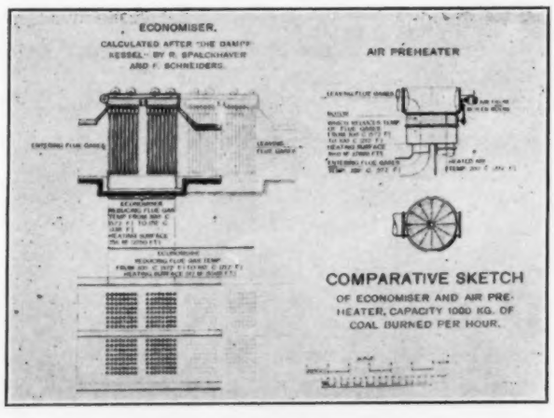

FIG. 19.

floor, the installation of the Ljungstrom Air Preheaters would, of course, also result in a considerably higher efficiency of the boiler plant as compared with the efficiency now obtained with the economizers. It should also be mentioned that the integral fans of the Preheater would replace the separate forced and induced draught fans now employed, at the same time greatly simplifying the control of the draught conditions in the boilers.

Fig. 16 shows the saving in floor space that can be obtained by installing Air Preheaters instead of economizers when designing a new power plant. The gain in floor space in this case amounts to about 25 per cent.

Fig. 17 shows the application of the Ljungstrom Air Preheater to two 3-furnace Scotch marine boilers on the Swedish steamer "Disa". In this case, one Air Preheater takes the gases from two boilers and supplies hot air to all the furnaces. Dampers have been provided for by-passing the heater when getting up steam.

In comparative tests on a sister ship, without Air Preheaters and with the Ljungstrom Air Preheaters, a saving in fuel of approximately 17½ per cent was obtained.

Fig. 18 shows the old type tubular heater previously built by James Howden & Company, Ltd., Glasgow, for

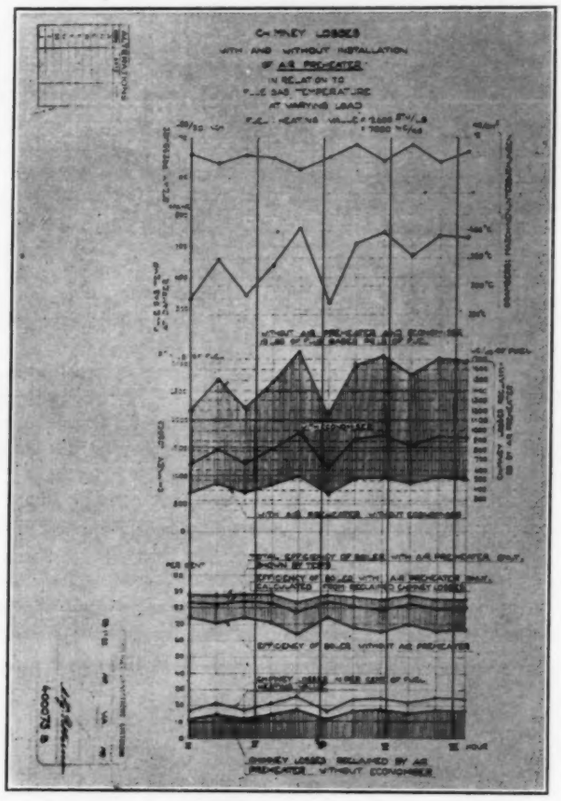

FIG. 20.

marine work. This heater shows an efficiency of about 25-30 per cent compared with about 70 per cent obtained with the Ljungstrom Preheater now being built by the same company. In this connection it may be interesting to know that the Howden Air Preheaters have been applied to boilers aggregating more than 26,000,000 hp.

At the present time we have about 100 Ljungstrom Air Preheaters running and under construction. About 20 of these are here in the United States. Preliminary tests on the first installation here show a saving in fuel of 15-17 per cent.

Comparison Between Economizers and Air Preheaters.

Fig. 19 shows the comparison between the Ljungstrom Air Preheater and an economizer of standard design, for a steam plant burning one ton of coal per

hour. The figures are drawn to the same scale and show plainly the very compact dimensions of the Air Preheater in comparison with an economizer. The full drawn heavy lines show the size of the economizer as usually built, while the light shaded lines show an economizer which would cool the flue gases down to the same temperature as that obtained after the Air Preheater.

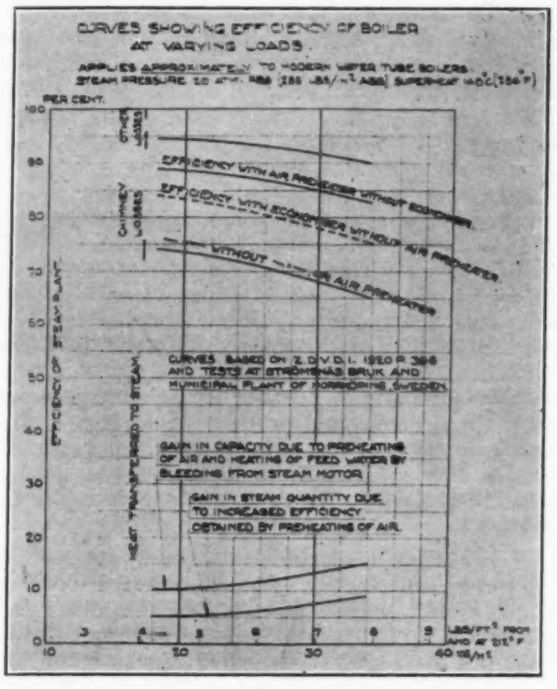
CURVES SHOWING EFFICIENCY OF BOILER AT VARYING LOADS
EFFICIENCY WITH AIR PREHEATER WITHOUT ECONOMIZER
EFFICIENCY WITH ECONOMIZER WITHOUT AIR PREHEATER
CURVES BASED ON Z. D. V. D. I. 1920 P. 388 AND TESTS AT STRÖMSNAS BRUK AND MUNICIPAL PLANT OF NORRKÖPING SWEDEN
GAIN IN CAPACITY DUE TO PREHEATING OF AIR AND HEATING OF FEED WATER BY BLEEDING FROM STEAM MOTOR
GAIN IN STEAM QUANTITY DUE TO INCREASED EFFICIENCY OBTAINED BY PREHEATING OF AIR
PER CENT.
EFFICIENCY OF STEAM PLANT
HEAT TRANSFERRED TO STEAM

FIG. 21.

With a heating surface of 2,750 ft., the economizer would reduce the flue gas temperature from about 572 deg. F. down to 338 deg. F., resulting in a saving in fuel of about 8.6 per cent. Starting with the same flue gas temperature, the Air Preheater reduces the gases down to about 212 deg., which according to tests corresponds to a fuel saving of 20.1 per cent. The total weight of the economizer tubes would be about 44,000 lbs. while the weight of the heating elements is 7,100 lbs. Thus the weight of the Air Preheater is only about one-sixth of the weight of the economizer while the saving in fuel is more than double.

As pointed out before, the economizer does not produce any saving above that due to the heat recovery from the flue gases. The Air Preheater, on the other hand, generally effects a saving much greater than that due to the recovered heat, which may be explained by the improved furnace conditions as well as the improved heat transference in the boiler.

Fig. 20 is a diagram showing the performance of a boiler under varying load. The upper part of the curve shows the variations in steam pressure. The second curve shows the corresponding flue gas temperatures. The middle part of the diagram shows the stack loss and the amount of heat that can be recovered by means of the Air Preheater, also, comparatively, the amount of the stack loss that can be recovered by means of an economizer. The lower part of the diagram shows the boiler efficiency without Air Preheater and the increase in boiler efficiency in connection with an Air Preheater. The lower part of the curve gives in percentage the stack loss and the heat recovery due to the Air Preheater.

These curves illustrate the great amount of heat recovered from the flue gases by means of the Air Preheater, producing an equalizing effect, too, as appears very plainly.

Investigation of the efficiency curves of the boiler shows that in this case the average efficiency without the Air Preheater is about 69 per cent, and with the Air Preheater about 85½ per cent, corresponding to an average saving of approximately 19½ per cent in fuel consumption.

As a rule a considerably greater fuel saving results during normal running conditions than that obtained under tests, because in the daily run the boiler without the Air Preheater generally is operated with much greater average chimney losses than those prevalent during the comparative tests when the firing and supervision is done by experts. With the Air Preheater in operation, the danger of lowering the efficiency of the boilers by careless firing, bad regulation, et cetera, is materially lessened in consequence of the improved furnace conditions, as well as due to the equalizing effect when heated combustion air is employed.

As an example I might mention a test showing a fuel saving of 20.1 per cent, whereas the fuel saving based on a comparison over the whole year showed an actual saving of about 25 per cent.

Fig. 21 shows typical efficiency curves obtained on modern high duty water tube boilers at various ratings. At about 125 per cent rating, the Air Preheater gives a fuel saving of about 17½ per cent, and the econo-

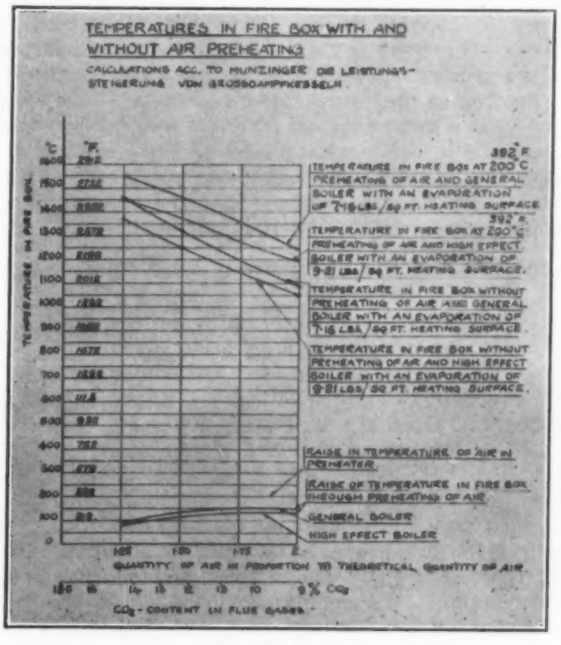
TEMPERATURES IN FIRE BOX WITH AND WITHOUT AIR PREHEATING
CALCULATIONS ACC. TO MUNZINGER DIE LEISTUNGS-STEIGERUNG VON GROSSDAMPFKESSELN
TEMPERATURE IN FIRE BOX AT 200°C PREHEATING OF AIR AND GENERAL BOILER WITH AN EVAPORATION OF 7.16 LBS./SQ FT. HEATING SURFACE
392° F
TEMPERATURE IN FIRE BOX AT 200°C PREHEATING OF AIR AND HIGH EFFECT BOILER WITH AN EVAPORATION OF 9.81 LBS./SQ FT. HEATING SURFACE.
TEMPERATURE IN FIRE BOX WITHOUT PREHEATING OF AIR AND GENERAL BOILER WITH AN EVAPORATION OF 7.16 LBS./SQ FT. HEATING SURFACE
TEMPERATURE IN FIRE BOX WITHOUT PREHEATING OF AIR AND HIGH EFFECT BOILER WITH AN EVAPORATION OF 9.81 LBS./SQ FT. HEATING SURFACE.
RAISE IN TEMPERATURE OF AIR IN PREHEATER
RAISE OF TEMPERATURE IN FIRE BOX THROUGH PREHEATING OF AIR
GENERAL BOILER
HIGH EFFECT BOILER
QUANTITY OF AIR IN PROPORTION TO THEORETICAL QUANTITY OF AIR
CO₂ - CONTENT IN FLUE GASES

FIG. 22.

mizer would probably give a saving of about 12 per cent. At a rating of 200 per cent, the saving obtained by the Air Preheater amounts to about 21 per cent, while the economizer would effect a saving of about 14 per cent. Consequently the saving in fuel due to the Air Preheater is apporximately 50 per cent greater than that possible with the economizer.

These efficiencies and fuel savings attained by the economizers are maximum values obtainable only in the case of modern high duty water tube boilers having a great part of the combined heating surface provided

for in the economizer. As appears from numerous tests the economizer generally effects a much lower saving than indicated in Fig. 21.

Another point apparent from Fig. 21 is that the economical rating of the boilers can be materially increased when an Air Preheater is used, due to the fact that the Air Preheater considerably raises the drooping part of the efficiency curve. From the lower part of the curve it appears that an increase in steam production of from 5 to 9 per cent above that obtained with the boiler and economizer using the same amount of fuel can be obtained, if an Air Preheater is installed instead of an economizer.

If preheating of combustion air is used in conjunction with stage bleeding for heating the feed water, an approximate gain in capacity of the plant amounting to from 10 to 15 per cent is possible without burning more coal, as indicated by the corresponding curve on Fig. 21.

Furnace Temperatures.

The upper part of Fig. 22 shows furnace temperatures at various CO_2 contents, or in other words, with varying excess air. The lower part of the curve shows the increase in furnace temperature corresponding to the preheating of the combustion air. With 25 per cent excess air, the increase in furnace temperature is about 45 per cent of the increase in temperature of the air, and with 75 per cent excess air, the increase in furnace temperature is about 65 per cent of the temperature increase of the air. In other words the actual increase in furnace temperature is considerably less than the increase in the temperature of the combustion air, the reason being that some of the added heat is absorbed by the radiant heat surfaces in the boiler at a rate corresponding to the fourth power of the absolute temperatures. The maximum air temperatures employed so far have been in the neighborhood of 600 deg., and we believe that considerably higher air temperatures can be successfully handled without any detrimental effect on properly designed stokers and furnaces.

Application of the Ljungstrom Air Preheater to Steel Mills.

Taking a case of a 1,000 hp. boiler operated at about 280 per cent rating, burning blast furnace gas with a heat value of 97 Btu./cu. ft., we would supply a C-16 Air Preheater. The temperature of the flue gases would be reduced from approximately 500 deg. F. to 226 deg. F., while the air temperature would be raised from 80 deg. F. to 396 deg. F., resulting in a saving in fuel of about 12 per cent.

This saving evaluated in coal of 11,500 Btu. at $5.00 per ton would probably amount to about $25,000 per year, depending, of course, on the load factor on the boiler.

On a 400 hp. Stirling boiler, operated at 200 per cent rating, a C-12 Air Preheater would be required. The waste gases are entering the Preheater at a temperature of 750 deg. F. heating the air to approximately 580 deg. F., corresponding to a saving of about 17.5 per cent in fuel.

An installation of a Ljungstrom Air Preheater in conjunction with a slab heating furnace is being made and it is expected that a very large saving in fuel will be obtained.

Summary of Advantages Obtainable by the Ljungstrom Air Preheater.

Greatly increased boiler efficiency = Saving in operating costs.

Ratings of boilers increased to the maximum = Saving in capital investment.

Possibility of operating boilers at high ratings with low grade fuel = Saving in fuel costs.

DISCUSSION

A. G. Witting: I would like to ask a question: How much of the air is transferred over into the waste gases and vice versa when the elements pass from one side to the other?

W. N. Flanagan: There is no question in my mind but what an air preheater is a logical thing to use with boiler providing other equipment will stand it. For instance, there is no question but what it will work on blast furnace gas, and there is no question but what it will work on certain types of stokers, particularly with low grade fuels. However, when you use preheated air, say, on an underfeed, which depends upon the incoming air to cool it, the question is how high the air temperature can be so that the stoker parts will be protected. In addition, when burning very high grade fuels which naturally give a high furnace temperature and you increase the incoming air temperature to high limits, 500 or 600 deg., the question is whether the furnace brick work and other parts will stand the additional flame temperature, without using water screens or water cooled walls or other devices.

A few other points come to mind. One is the effectiveness of the cleaning of the heater elements when burning coal. Another is in connection with a question that Mr. Witting asked, in connection with the fans shown, whether the type of fan which Mr. Brolinson showed would be sufficient for a boiler with a high draft loss. Some boilers that are in operation around here have 4 to 7 in. of draft loss through them. Others may only have two. Other types of stokers require as high as 7 in. pressures under fire for combustion. My question is whether that type of fan would produce that desired air pressure and that desired draft.

In connection with 545 and 600 deg. air temperatures I would like to ask Mr. Brolinson what the temperature leaving the boiler is. It must be pretty high.

It was a very interesting experience in a preliminary test on an air preheater to note that with preheated air on a blast furnace gas fired boiler and a higher combustion chamber temperature we maintained a lower stack temperature than without preheated air, showing that the heat transferred to the boiler tubes by radiation from the combustion chamber was that much greater and kept the stack temperature down even with the higher initial temperature. Thus the difference in flame temperature was a clear gain.

H. C. Seibert: Mr. Brolinson mentioned the application of air preheaters in the metallurgical furnaces. I would like to ask whether he means applying the preheater directly to preheating the air for combustion by means of passing the exit gases through the preheater or whether he means preheating the air for the waste heat boiler in connection with the furnace? If the thing is to be used directly in connection with the heating furnace, I would like to point out or rather I would like to ask Mr. Brolinson how a mechanism of that type could withstand a temperature of 2,000 deg. and even above? You know the critical temperature of steel is around 1650.

J. B. Crane: I was wondering whether on these questions of efficiency they were using the low heat or

the high heat value of coal? We find on a great many of these European tests where they show particularly high boiler efficiency that they have used the low heat value of coal. They do not charge against the boiler the Btu. in the hydrogen as that is evaporated and is not used.

A. G. Witting: When we theorize about heat efficiency, it is too often forgotten that there is a very important factor that can not be expressed in figures. I might be accused of anticipating a paper that will later on be read, in which this factor is emphasized, but it has such an important bearing on the subject under discussion and, in a general way, such an important bearing on all combustion problems that I hope I will be excused for taking it up prematurely.

This factor is the influence of an increased temperature of combustion (whether the result of concentrated combustion, a reduction of the time element which does not enter into the formulas for developed heat, or the result of preheating) which, as experience has proven, increases the efficiency out of measure with the additional heat carried by the gases or with the decreased chances for heat dissemination through convection or radiation.

Due to this fact the recovering of heat for instance from the waste gases in a boiler by the air to be used for the combustion instead of by the feed water undoubtedly will show a considerable gain in heat efficiency which can not be expressed by any calculation.

The primary assumption is of course that an air preheater will be able to reduce the temperature of the waste gases as much and let the air absorb as many heat units as it is possible to absorb by the feed water in an economizer. When the water in this manner is additionally heated by a certain amount of heat units thus transferred, it simply means that the water will need the very same heat units less to be converted into steam, and the fuel consumption will be reduced to the very same extent. But when the same heat units are returned to the boiler with the air it does first of all mean that the corresponding amount of heat developed by the combustion of certain amount of fuel will be saved. But in addition it means that the flame temperatures will be increased perhaps a 100 deg. F. or more. And this increase in the temperature will, without doubt, effect an additional and perhaps considerable saving which otherwise can not be obtained. The principle of recovering heat from the waste gases by the air instead of by the feed water is consequently the correct one, and its practical application will mean another step forward to greater fuel efficiency.

Difficulties will be encountered that must be overcome and I am of course not in any position to judge to what extent this has been accomplished by the Ljungstrom Air Preheater. The ability of the heat exchanger to withstand the heat, the effect of soot carried by the waste gases, which is one of the greatest troubles with feed water economizers, the maintenance of the apparatus and of its efficiency, will very greatly affect its value, just as, possibly, the difference in first cost and in the cost of operation might offset the gain in fuel economy. But these are problems to be solved, if they have not already been solved. What I want to emphasize is that by preheating the air you will not only be able to reclaim as much of the heat carried away by the waste gases as in any other manner, but besides obtain as an extra bonus a higher temperature of combustion from which an increased fuel efficiency will result, a fact that eludes our calculations.

B. G. Brolinson: Regarding Mr. Witting's questions. Of course, we quite agree with this gentleman that we get more out of the preheated air than we would get if we used the same amount of heat in the economizer. This is due to the improved and livelier combustion and also because of the better heat transference in the boiler. We note also that the radiant heat transference in the boiler increases with the fourth power of the absolute furnace temperature. That, of course, has a whole lot to do with the highly increased boiler efficiency with preheated air.

Regarding stoker upkeep. We have been using the Ljungstrom air preheater in connection with chain grate stokers, also with underfed stokers and hand fired boilers of various types. The maximum air temperatures we have used so far are about 600 deg., and we have not experienced any trouble due to the heated air. We also have found out from some of the stoker manufacturers here that they would not be afraid of about 700 deg. air temperatures under the stokers.

In the case where you have high grade fuel. You can regulate your furnace temperature by varying your CO_2 content. In our case, assume that you decrease your CO_2 contents from 14 to 10 per cent, taking that as an example. In the ordinary case, you would, of course, increase your stack loss considerably, but if you regain 70 per cent of your stack loss, you will find that you really did not decrease your boiler efficiency, except for the small part of the non-recoverable heat between the temperature of the leaving flue gases and incoming air. That means a very small amount. So right there you have a means of regulating your furnace temperature. You can also vary your furnace temperature by means of secondary air. When using preheated air, you can employ secondary air without disturbing your combustion.

Regarding high furnace temperatures. In some cases you have to use water screens anyway, and of course, in this case, you would get along with a smaller size boiler running at higher rating. Water screens have some advantages.

Regarding the fans. We can use our fans under ordinary conditions up to five inches on each side. That means five inches on the air fan and five inches on the flue gas fan, or about 10 in. altogether. But in extreme cases we can design our fan to take care of, say, about six or seven inches on the air side, so it is a question of strength of the fans.

W. Flanagan: What fan efficiency?

B. G. Brolinson: The efficiency of the propeller fan is not so low as you would think. One of the most efficient fans used in Germany, the Betz fan, is a propeller fan designed like an aeroplane propeller, having about 75 per cent efficiency over quite a wide range. This fan was developed during the war. You can get very good efficiency on the propeller fan if you design it properly.

Regarding the metallurgical furnaces. There are two ways the air preheater could be applied to steel furnaces. The first way is the direct way and would be to take the flue gases from the slab heating furnaces, for instance. In some cases we take the flue gases from one furnace and passing them through the air preheater, use the preheated air under two furnaces. That means that we use the preheated air for combustion directly.

Another application of the air preheater in steel mills would be to use it in connection with boilers burning blast furnace gas, or some other waste heat gas. That

would simply mean that we use the preheater in connection with the waste heat boiler returning a certain amount of heat units back to the furnace.

Regarding the lower and higher heat values. Some of the curves I showed were based on lower heat values, or as they call it, the effective heat value, but I mentioned in most cases that they were based on gross heat value, as fired. For instance, the Metropolitan tests were based on gross heat values as fired, the efficiency being increased from 74.5 per cent to 84 per cent on old B. & W. boilers with small furnaces. The oil burning tests showed an efficiency of 90.7 per cent based on gross heat value.

Another point regarding the temperatures. In the case of the 1,200 hp. steel mill boiler, we figured an incoming flue gas temperature of 500 deg. The gas temperature after the heater would be 226 deg. The air temperature would be 396 deg. after the heater and 80 deg. before the heater.

In the case of the 400 hp. Sterling boiler, entering flue gas temperature was 750 deg. That is unusually high, of course, but these are actual figures supplied to us. The air would be heated up to 580 deg. In this case we would show a saving of about 17½ per cent in fuel.

H. C. Siebert: I think there is a slight misunderstanding on the question that I raised. I asked Mr. Brolinson whether in the case of metallurgical heating furnaces having exit temperatures of 2,000 deg.—and may have that and even higher temperatures, depending upon the rating at which they are running—whether he would recommend passing the waste gases at 2,000 deg. into the preheater he has shown, or recommend first passing those gases through the boiler and then the waste gases from the boiler through the preheater?

B. G. Brolinson: That depends on conditions. In some cases the waste gas temperatures vary and we would probably supply a sort of recuperating or equalizing chamber. In the case of constant temperatures, we would perhaps use a waste heat boiler first and then the air preheater. Another way which we use sometimes is to let in some cold air in order to reduce the maximum temperatures.

Value Increases Faster Than Cost

By HARRINGTON EMERSON*

MR. President and Gentlemen: The reason I came in this morning is because you are engaged in producing values which increase faster than cost. That law is a universal law. It applies not only to equipment, it applies also to materials; it applies also to human beings, people, and it isn't recognized nearly to the extent that it deserves.

To give you a few examples: You know that in a lathe or planer a tool of high speed steel will cut perhaps 100 times as much as a piece of carbon steel, yet you can buy it for a dollar a pound against 20 cents a pound for the old carbon steel. I would rather pay $2,000 a pound for high speed steel than not have it but I can get it for $1, and yet its real value is in the neighborhood of $2,000. The same law of value increasing faster than cost is true of a sewing machine. A sewing machine would be worth $50,000 if you couldn't buy it for less, because a single sewing machine will do as much work as a hundred women.

The same law is true of human beings. A human being's value increases immeasurably faster than his cost.

The chart illustrates the law, "Values increase faster than cost."

Curve I is the line of increasing cost. It is a straight line.

Curve II illustrates values relative to cost line I.

At point O value equals cost.

Beyond O value increases faster than cost. To the left of O value decreases faster than cost and may even be negative as illustrated.

A great many of us are obsessed with the fear of cost and therefore are working in the region of point O. The farther we can get to the right of O, the greater will be the value received per unit of cost, which should be the aim.

*Emerson Engineers, New York City.

The law is just as true of people as it is of materials and equipment.

One important reason why we work at the wrong end of the chart is illustrated by the Supply Line Curve III. At low cost (salary, wages) we have an enormous supply of men, while at high cost the supply is very limited. It is much easier to work on a low wage basis with large numbers than to work on a

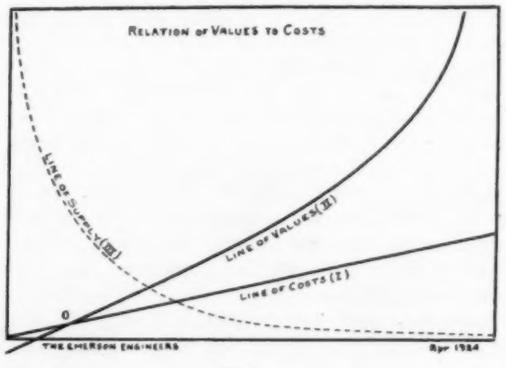

FIG. 1.

higher wage basis with smaller numbers, but it is more economical (cheaper) to work on the latter plan.

The aim that all should have is to find that man of tremendous value at relatively low cost.

The trouble is that the problem is generally attacked from the cost side rather than the value side, which is the correct method.

First determine the values you want and then decide what you can pay for it.

The farther we can work to the right of point O, the greater will be the value received per unit cost.

Several years ago I was visiting the Ford plant. Mr. Ford is probably the greatest industrial genius

who ever lived. In his plant I was introduced to a man, an extraordinarily able man. I asked him whether he would exchange counseling with me—whether I could consult him about modern conditions and he in turn consult me. "I have a staff of specialists; I call them my consulting staff. I would like to add you to them."

When I left, the young man accompanying me said, "Do you know how much salary that man earned last year?"

"I suppose he earned $25,000 a year, perhaps $50,000."

"He received last year $420,000."

I had made the best trade in my life, that particular one. (Laughter.) By his plan he had increased the sale of Ford cars over 100,000 above what they had been the year previous, and he was paid $3 for each extra motor that was sold. That made a $300,000 bonus, which he received above his salary.

Mr. Ford didn't give him one single dollar of this bonus until the cars had been sold and the money was in hand. Mr. Ford made about $100 on each car sold, so that Mr. Ford had $10,000,000 in hand, actually in his pockets, before he paid this gentleman the $300,000 that amounted to three per cent.

This is an example of Mr. Ford's wisdom. He knew that the cheapest man he could find anywhere in the United States was the man to whom he gave $420,000.

I am certain that you gentlemen who are engaged in increasing the value line at a much smaller increase in the cost line will not object to my view that there is no salary so large that it may not be justified if correspondingly greater value is delivered.

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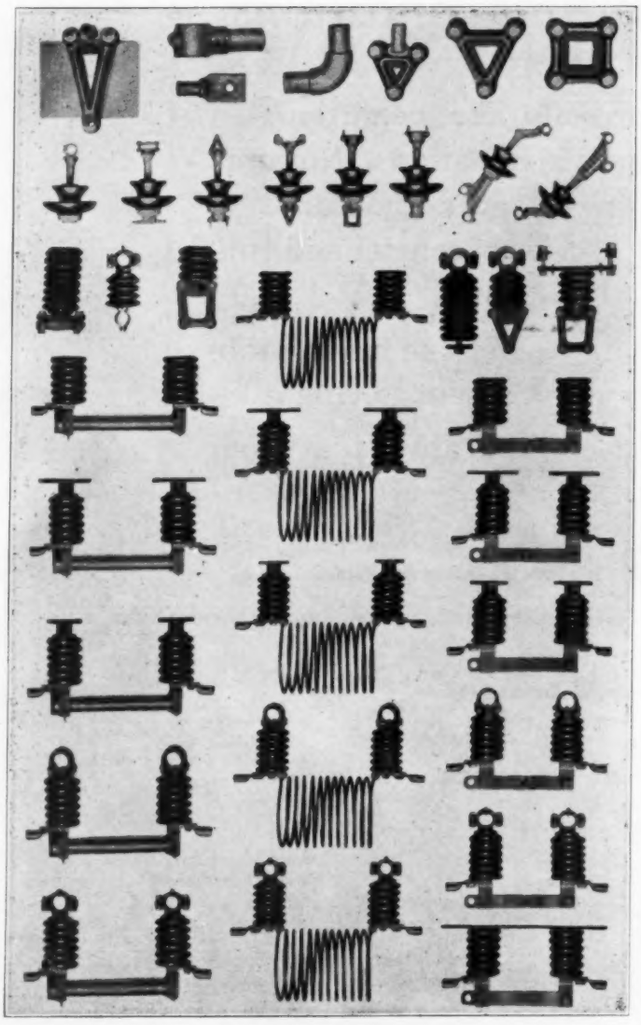

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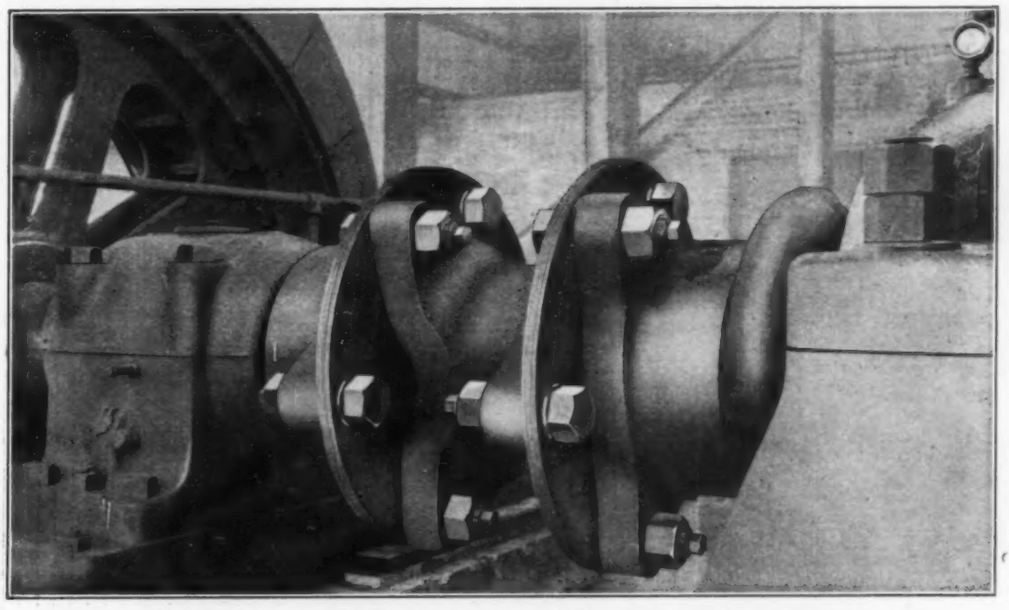

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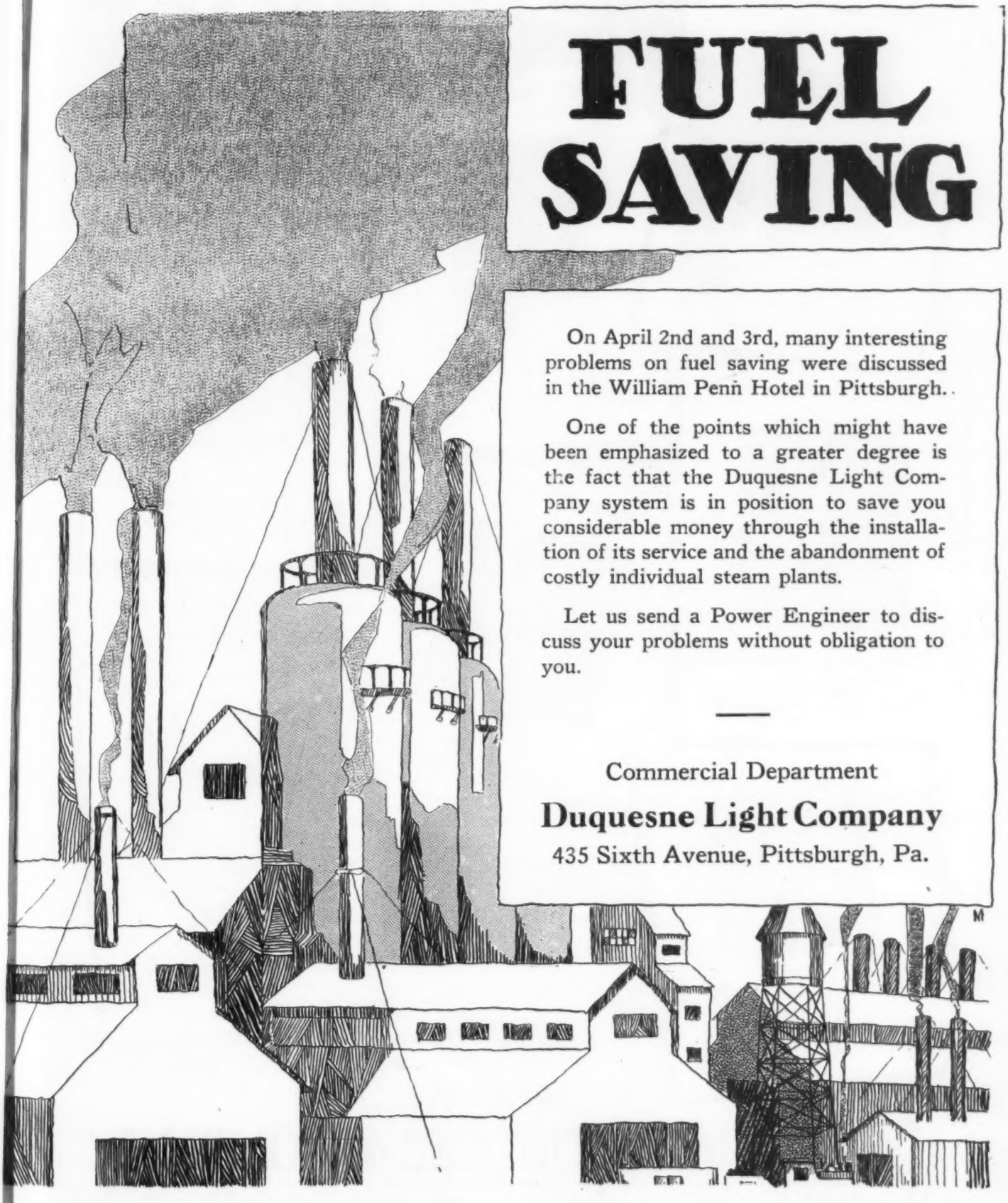
Economy Fuses were the first line using an inexpensive bare renewal link for restoring a blown fuse to its original efficency to be Approved in All Capacities by the Underwriters' Laboratories.

ECONOMY *renewable* FUSES



FUEL SAVING

On April 2nd and 3rd, many interesting problems on fuel saving were discussed in the William Penn Hotel in Pittsburgh.

One of the points which might have been emphasized to a greater degree is the fact that the Duquesne Light Company system is in position to save you considerable money through the installation of its service and the abandonment of costly individual steam plants.

Let us send a Power Engineer to discuss your problems without obligation to you.

Commercial Department

Duquesne Light Company

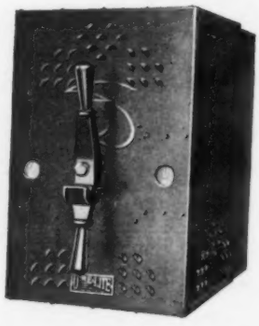
435 Sixth Avenue, Pittsburgh, Pa.

U-RE-LITE

U-RE-LITE Jr. (*250 volts D. C.*)
1 to 60 amps. inclusive.
Features: Overload or overload and Dalite (Direct acting Time limit)

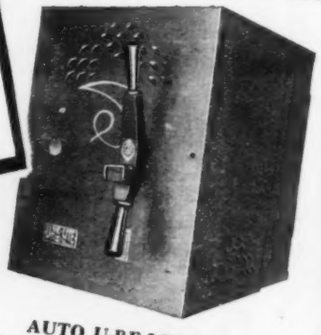
U-RE-LITE Sr. (*250 volts D. C.*)
5 to 200 amps. inclusive
Features: Overload - Dalite (Direct acting Time limit.) No voltage or shunt trip. Bell ringer.

U-RE-LITE "W" (*250 volts D. C.*)
5 to 400 amps. inclusive.
Features: Overload - Dalite (Direct acting Time limit.) No voltage or shunt trip. Bell ringer.



U-RE-LITE "NX" (*250 volts D. C.*)
100 to 1250 amps. inclusive.
Features: Overload - Dalite (Direct acting Time limit.) No voltage or shunt trip. Bell ringer.

AUTO U-RE-LITE Sr.
5 to 150 amps. inc. at 220 volts A. C.
5 to 80 amps. inc. at 550 volts A. C.
Features: Overload - Dalite (Direct acting Time limit.) No voltage or shunt trip. Bell ringer.

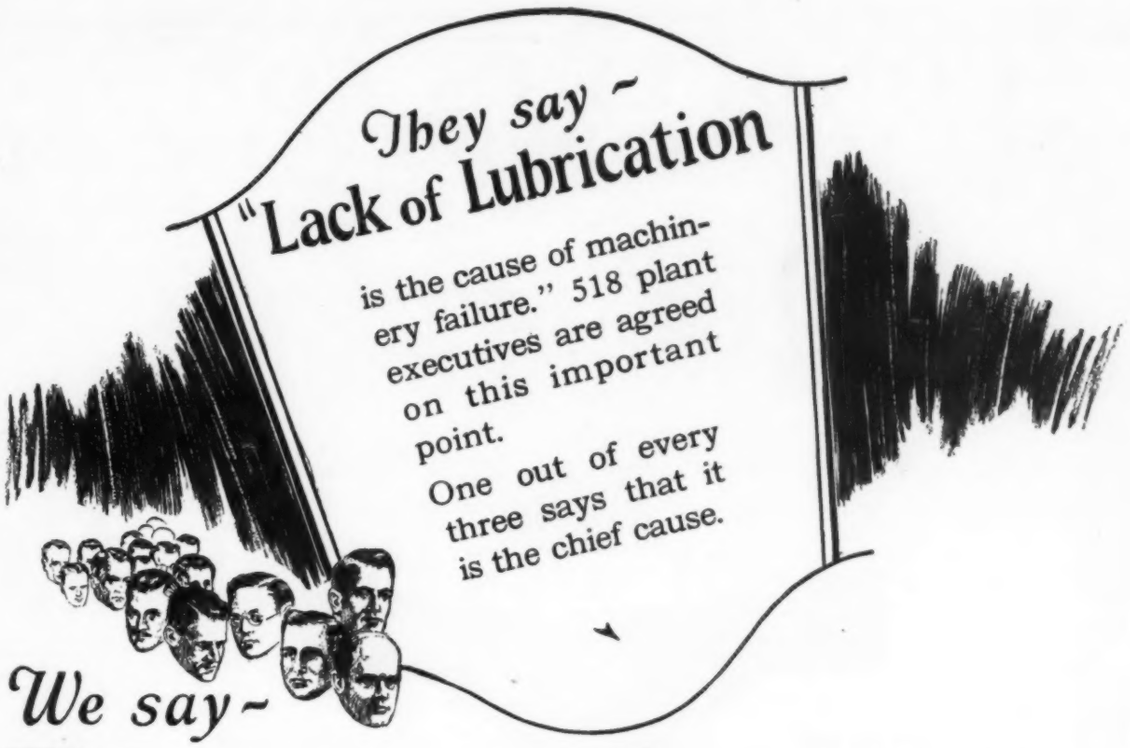


AUTO U-RE-LITE "W"
5 to 400 amps. inc. at 220 volts A. C.
5 to 300 amps. inc. at 550 volts A. C.
Features: Overload - Dalite (Direct acting Time limit.) No voltage or shunt trip. Bell ringer

AUTO U-RE-LITE Jr.
1 to 60 amps. inc. at 220 volts A. C.
1 to 15 amps. inc. at 550 volts A. C.
Features: Overload - Dalite (Direct acting Time limit.) No voltage or shunt trip. Bell ringer

CIRCUIT BREAKER ENGINEERS To AMERICAN INDUSTRY

The CUTTER-HTE COMPANY
ESTABLISHED 1888 PHILADELPHIA


They say ~
"Lack of Lubrication
is the cause of machinery failure." 518 plant executives are agreed on this important point.
One out of every three says that it is the chief cause.
We say ~

This now can be overcome

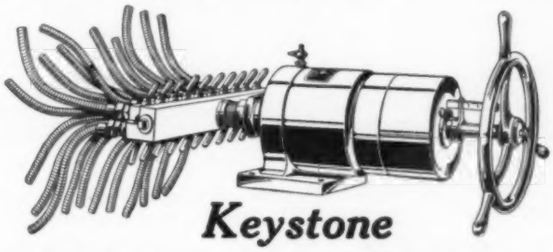
here's how

YOU provide lasting protection against lack of lubrication by equipping your machinery with the Keystone Manifold Safety Lubricator.

The Keystone Manifold Safety Lubricator represents the most advanced form of easy, safe and *positive* lubrication so far perfected.

From one central, safe, convenient place the operator turns the wheel and lubricates the entire machine. Keystone Grease is forced under high pressure thru pipe line leads directly to the bearings. No waste of lubricant, no risk to operator's life or limbs, no dirt or grit in bearings, no shut-downs for lubrication, no excuse for neglect.

The price you pay for lack of lubrication is heavier than the cost of prevention. Get details—write!



KEYSTONE GREASE

Keystone

Manifold Safety Lubricator

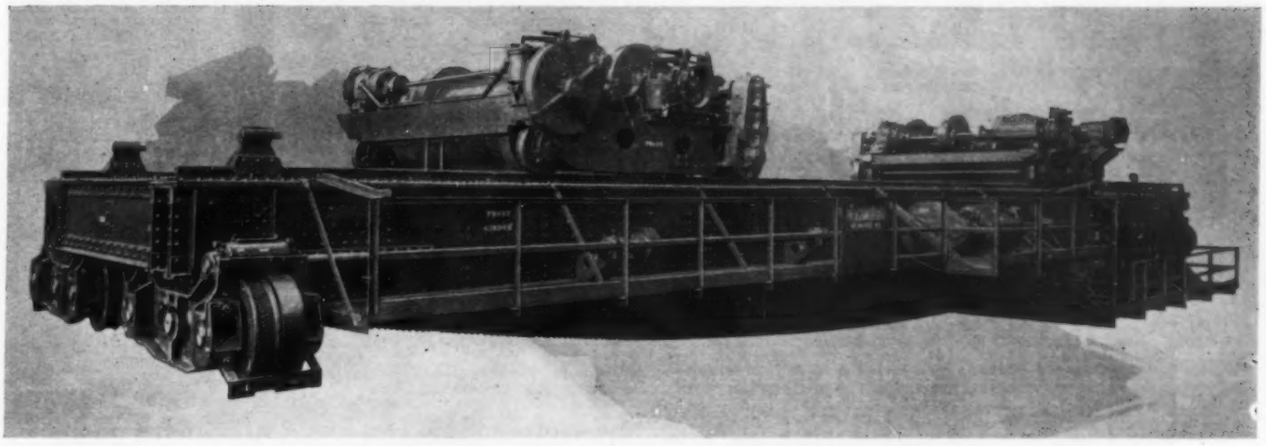
MULTIPLE FEED, HIGH-PRESSURE GREASE LUBRICATING SYSTEM

THE KEYSTONE LUBRICATING CO. *Established 1884* **at 21st and Clearfield Streets, Philadelphia**

CONDULETS FOR CONCEALED CONDUIT SYSTEM

ET
TYPE ET
FOR LOOPS
SAVES LABOR
AND CONDUIT
ELB
TYPE ELB
90° ELBOWS
EY
TYPE EY
FOR BRANCHES
Junctions in conduit systems may be made at points which later may be concealed or inaccessible.
A single run of conduit is made from the Condulet to the outlet where the necessary splices or taps can be made.
C H 120

CROUSE-HINDS COMPANY
SYRACUSE, N.Y., U.S.A.



200-Ton Capacity P & H Mill Type Crane. P & H Crane Craftsmanship is apparent not only in the complete crane but in every part.

Dependable, Fast Crane Service

As a result of P & H Crane craftsmanship, 40 years' manufacturing experience, and plant equipment second to none in every respect—P & H Cranes and Hoists provide the utmost in dependability.

The fact that over 7300 of these material handling cranes are in use is evidence that industrial men have recognized the value of the P & H quality of design and construction. Long years of service have demonstrated over and over again the low maintenance, ruggedness, and efficiency—which mean lower crane and service costs.

There is a precision, an effortless ease and dependability about P & H Cranes (large or small) that place them quite apart. And back of every crane is the service possible through a time-tried organization and adequately equipped plant.

P & H Grab Bucket Hoists because of higher hoisting and lowering speeds increase amount of material handled per hour. They handle more at lower power and maintenance costs. Send for special Grab Bucket Bulletin.

Front Lever Control Safety Cage

P & H has also developed the safety cage with front lever control, giving the operator unobstructed view, increasing the speed of handling. All switch and control parts are entirely enclosed in a cabinet so that there is no chance of coming into contact with live parts.

Bulletin 408 containing complete data and illustrations will be mailed on request.

Crane and Hoist Division

PAWLING & HARNISCHFEGER CO.

Established in 1884

3855 National Avenue, Milwaukee, Wis.

New York, Atlanta, Detroit, Kansas City, Chicago, Portland, Memphis, Dallas, Philadelphia, Pittsburgh, Los Angeles, San Francisco, Seattle

P&H CRANES and HOISTS

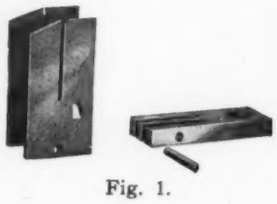


Fig. 1.

Fig. 2.

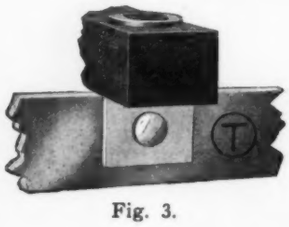


Fig. 3.

Fig. 4.

Iron and Steel Electrical Engineers:

You Iron and Steel Engineers represent probably the first body of men who individually and collectively appreciated that to obtain safety in switches something far more was necessary than just a safety box.

No body of men know better than you the unfortunate position in which safety switches have been placed because of a long drawn propaganda by salesmen and press eulogizing the safety box which keeps the operator away from the live parts of the switch. Such propaganda paid no attention whatever to the first necessity of safety in switches—namely the type of switch in the box that is to do the work.

From the beginning until now, there are few manufacturers and fewer contractors and engineers who pay enough attention to the construction of the knife switch proper, thinking as they do that safety switches mean a safety box surrounding most any kind of a switch.

Even the Underwriters in classifying safety switches speak of Class A, Class B, Class C or even Class AA in terms of boxes only—disregarding the switch entirely—an A box may contain the cheapest switch imaginable. One safe switch for industrial use is the Trumbull Type A manufactured for nearly twenty-five years. The Trumbull type A switch is machine made—built-up, most rigidly constructed and **quick-make** and **quick-break.** It will stand up under use and abuse.

The Illustrations Show

Figure 1—Foot-block and the pin that fastens the blades to the foot-block after it has been sweated.

Figure 2—Shows contact jaw complete.

Figure 3—Shows method of fastening the blade to the fibre cross-bar, making a unit of the blade and crossbar.

Figure 4—Shows long and strong quick make quick break spring that at no time is worked more than 50 per cent of its capacity.

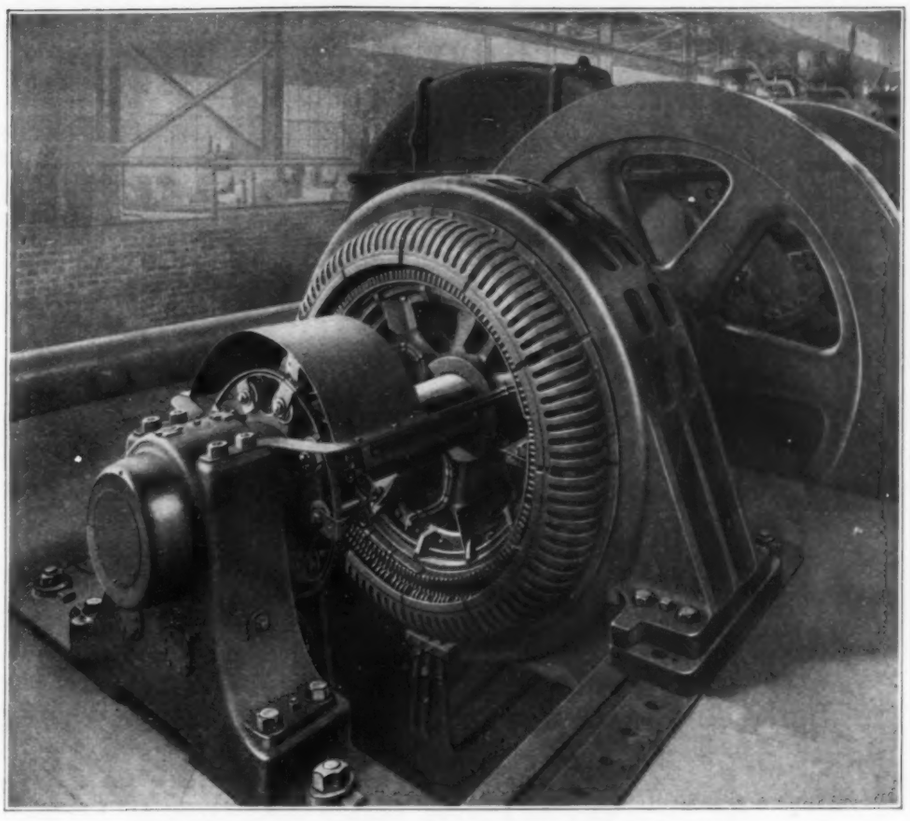
The Trumbull Electric Mfg. Company

114 Liberty St., New York City
595 Mission St., San Francisco, Cal.

Plainville, Conn.

2001 W. Pershing Rd., Chicago, Ill.
Boston Philadelphia Atlanta

ALLIS-CHALMERS



1000 HP. 250 R.P.M. Sheet Mill Induction Motor

Sheet Mill Drive

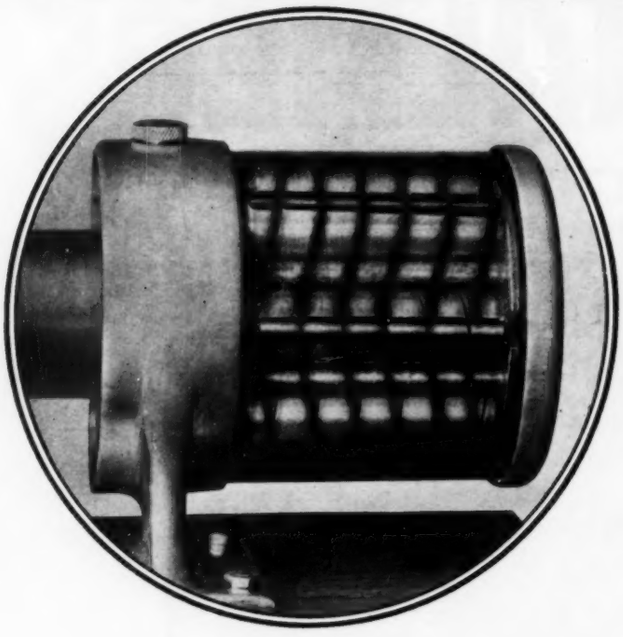
An Allis-Chalmers Induction Motor with Automatic Liquid Slip Regulator Control giving unexcelled service in large Eastern Steel Plant.

ALLIS-CHALMERS PRODUCTS
Electrical Machinery
Steam Turbines
Steam Engines
Gas and Oil Engines
Hydraulic Turbines
Crushing and Cement Machinery
Mining Machinery

ALLIS-CHALMERS MANUFACTURING COMPANY

MILWAUKEE, WISCONSIN, U.S.A.

ALLIS-CHALMERS PRODUCTS
Flour and Saw Mill Machinery
Power Transmission Machinery
Pumping Engines-Centrifugal Pumps
Steam and Electric Hoists
Air Compressors - Air Brakes
Agricultural Machinery
Condensers



Why Hyatt roller bearings have positive lubrication

The helically wound rollers are assembled alternately right hand and left hand. As the bearing operates the lubricant flows through the slots in the rollers and is swept back and forth across the bearing surfaces as shown in this unretouched photograph of a glass-enclosed working model. Every part of the bearing is lubricated as long as there is even a small quantity of lubricant in the housing.

Positive Lubrication And Cleanliness

Any electric motor in which these two features are properly provided for is assured of economical and uninterrupted performance.

Positive lubrication of Hyatt roller bearings is secured by using either oil or grease. Because of their accuracy and unappreciable wear, even after years of service, Hyatt bearings can be mounted in housings with very small shaft clearances.

These small clearances keep oil and grease out of the motor windings, and prevent dust and dirt from getting into the bearings. Troubles from impaired insulation and from the bearings themselves are thereby practically eliminated.

HYATT ROLLER BEARING COMPANY
NEWARK, NEW JERSEY

HYATT ROLLER BEARINGS FOR ELECTRIC MOTORS

Nuttall

Nuttall Type B Flexible Coupling

Type B Spring Buffer Coupling

This is an especially rugged, cast steel, spring buffer coupling, adapted to heavy loads and moderate speeds. It is reversible and is a wonderful shock absorber. Half its springs are in compression and half in tension in either direction of rotation.

It is exceedingly simple to install and one half may be removed without removing the other. It is made in twelve sizes good for transmitting from 100 to 4900 horsepower, at speeds from 200 to 1200 rpm. Bores range from 3″ to 18½″.

Send for Complete Catalog

R.D. NUTTALL COMPANY
PITTSBURGH PENNSYLVANIA

Philadelphia Office
420 Land Title Bldg.

Chicago Office
2133 Conway Bldg.

HOFFMANN PRECISION ROLLER BEARINGS

For Heavy Loads and Hard Service

Heavy-duty units manufactured to unequaled standards of precision; affording the maximum of serviceability under conditions involving heavy loads, temporary overloads, shock, jar and vibration; offering to manufacturers and users of electrical machinery for the steel plant new opportunities for power saving, reduced upkeep costs, and better service.

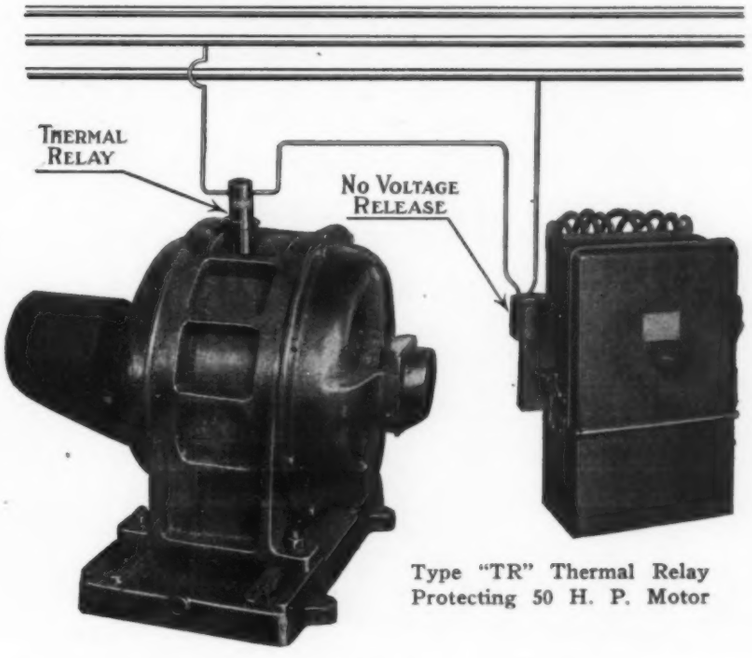
Our engineers will welcome an opportunity to work with yours, in applying these high-duty, high-precision bearings to your machines, with a view to securing maximum anti-friction efficiency, minimum maintenance costs, and continuity of service.

THE NORMA COMPANY OF AMERICA
Anable Avenue
Long Island City New York
MAKERS OF "NORMA" PRECISION BALL BEARINGS

ALL SPEEDS and POWERS

STANDARD and SELF-ALIGNING TYPES

MOTOR PROTECTION BASED ON MOTOR TEMPERATURE IS CORRECT



Type "TR" Thermal Relay
Protecting 50 H. P. Motor

IT IS ALSO

SIMPLE - EFFECTIVE - RELIABLE - INEXPENSIVE

AND

EASY TO INSTALL

A TYPE "TR" THERMAL RELAY TO PROTECT THE RUNNING MOTOR

AGAINST

1—Roasting out
2—Phase Failure
3—Continuous Overload
4—Mechanical Friction
5—Worn out Bearings
6—Rotor Dragging on Stator

+

OVERLOAD RELAYS OR FUSES TO PROTECT THE STALLED MOTOR

And you have COMPLETE and RELIABLE MOTOR PROTECTION at a very low cost.

Bulletin 402-F Gives Details.

THE AUTOMATIC RECLOSING CIRCUIT BREAKER CO.

COLUMBUS, OHIO

PITTSBURGH: 223 Oliver Bldg.
ST. LOUIS: 401 National Bank of Commerce Bldg.
WILKES-BARRE, PA.: 816 Miners Bank Bldg.
CHARLESTON, W. VA.: 317-318 Moore Bldg.

Our Representative will be glad to discuss
Fynn-Weichsel Motors for your plant.

POW-R-FULL
Starterless Motors
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Single-Phase Motors

Fractional Horsepower Motors

FYNN-WEICHSEL
Synchronous Induction Polyphase
"The Motor that Corrects Power Factor"

POW-R-FULL
Induction Motors
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Transformers, Power and Distribution

WHITE-LIGHT
Converters

Automotive Starting Lighting and Ignition

LUDWIG HOMMEL & CO.

929 Penn Ave.
PITTSBURGH, PA.

LUDWIG HOMMEL & CO.

Rose Building
CLEVELAND, O.

IMPROVEMENT *in* POLYPHASE METERING

THE latest addition to the Sangamo family is a horizontal polyphase meter, which comprises two completely independent Sangamo Type-H single-phase elements geared to a differential train that totalizes on a single register the algebraic sum of the energy measurements of the two meters.

Electrically and magnetically the two elements are entirely independent and each may be calibrated exactly like a single-phase meter and adjusted without reference to the other, the operation taking less time and less equipment than is ordinarily required for calibrating polyphase meters.

All parts except the register are interchangeable with standard Sangamo Type-H single-phase meters.

The independent unit method of construction makes it impossible for an open-potential circuit on either leg to go unnoticed as the element on the open leg will stop immediately.

Because of the wide interest in power-factor, arrangements have been made to facilitate power-factor measurements; a graph on the terminal box door permits the immediate translation of disk revolutions into the power-factor.

Complete and detailed information regarding this meter will be furnished upon request.

SANGAMO METERS

SANGAMO ELECTRIC COMPANY, SPRINGFIELD, ILLINOIS

NEW YORK · CHICAGO · BIRMINGHAM · SAN FRANCISCO · LOS ANGELES

METERS *for* EVERY ELECTRICAL NEED

6220-1

Do you know the advantages of a Strom Ball Bearing equipped motor?

Engineers will tell you that an electric motor equipped with Strom Ball Bearings has the following important advantages. All of which tend to give uninterrupted service.

Ball Bearings insure a permanent and uniform air gap between armature and coils because the wear of ball bearings is negligible.

Insulation troubles caused by oil leakage are eliminated because housings can be specially constructed for retention of lubricants.

Starting and running resistance are reduced and equalized.

More compact motor design is possible because of small bearing width space required.

End motion of rotor in the field disappears because Strom Ball Bearings take end thrust as well as radial load.

Freedom from vibration increases life of the motor. Maintenance and service costs are lowered.

Strom Ball Bearings are made in a wide range of types and sizes for practically any installation. The services of our engineers are at your disposal always. Consult them without obligation.

Strom BALL BEARINGS

Manufactured by

STROM BALL BEARING MFG. CO.
Formerly U. S. Ball Bearing Mfg. Co.
4594 Palmer Street, Chicago, Ill.

Double-acting thrust bearing, flat seats (grooved races) 2100-F Series

Single-acting thrust bearing, flat seats (grooved races) 1100-F Series

Single-acting, self-aligning thrust bearing 1100 Series

Single-acting, self-aligning thrust bearing, leveling washer. 1100-U Series

Double-acting, self-aligning thrust bearing, leveling washers 2100-U Series

Single-row deep-groove Standard type, radial bearing

Double-row, deep-groove Standard type, radial bearing

Angular contact bearing, combination radial and thrust

Double-row, maximum type, radial bearing

Single-row, maximum type, radial bearing

The Largest Boilers Installed Outside of the United States are Ladd Boilers—

A little over a year ago four 1735 H.P. LADD BOILERS were installed at the Vitry Station of the Union d'Electricite at Paris, France. These boilers were the largest boilers installed anywhere outside of the United States and were so successful that when this same company decided to enlarge their Gennevilliers Station the same type of boiler was chosen but of greater capacity, being rated at 1975 H.P., and four of these are now being installed.

As a further result of the installation at Vitry an order has now been received for two LADD Boilers of 2260 H.P. each from the Cie Parisienne de Distribution d'Electricite, for their St. Ouen Station at Paris, France.

These three stations contain the largest boilers installed outside of the United States.

May we co-operate with you?

THE GEORGE T. LADD COMPANY

First National Bank Building
PITTSBURGH, PA.

CHICAGO OFFICE: 528 McCormick Building
NEW YORK OFFICE: 39 Cortlandt Street
PHILADELPHIA OFFICE: 502 Franklin Bank Building

WATER TUBE BOILER LADD

BENJAMIN

They Get the Man!

In Steel Mills, Foundries, Forge Shops and Metal Working Plants, or wherever the noises of operation are so great that it takes an unusual signal to penetrate the din.

Benjamin Industrial Signals

in connection with any system of calling, get through, over and around the noise of machinery. They have a clear, penetrating tone that summons the busy superintendent or foreman without delay. They start men at their tasks promptly and call time without confusion. They may be used as general warning signals or for emergency or automatic calls in connection with specific operations.

For both direct and alternating current. Heavy duty weatherproof and heavy duty non-weatherproof. Used with the Benjamin Telecode Relay, and despite all industrial noises, they bring the telephone call to the remotest part of the plant.

Our nearest office will gladly demonstrate and give full information

BENJAMIN ELECTRIC MFG. CO.

247 W. 17th St. New York — 847 W. Jackson Blvd. Chicago — 580 Howard St. San Francisco

Enameled Steel Reflectors
Factory Lighting Fixtures
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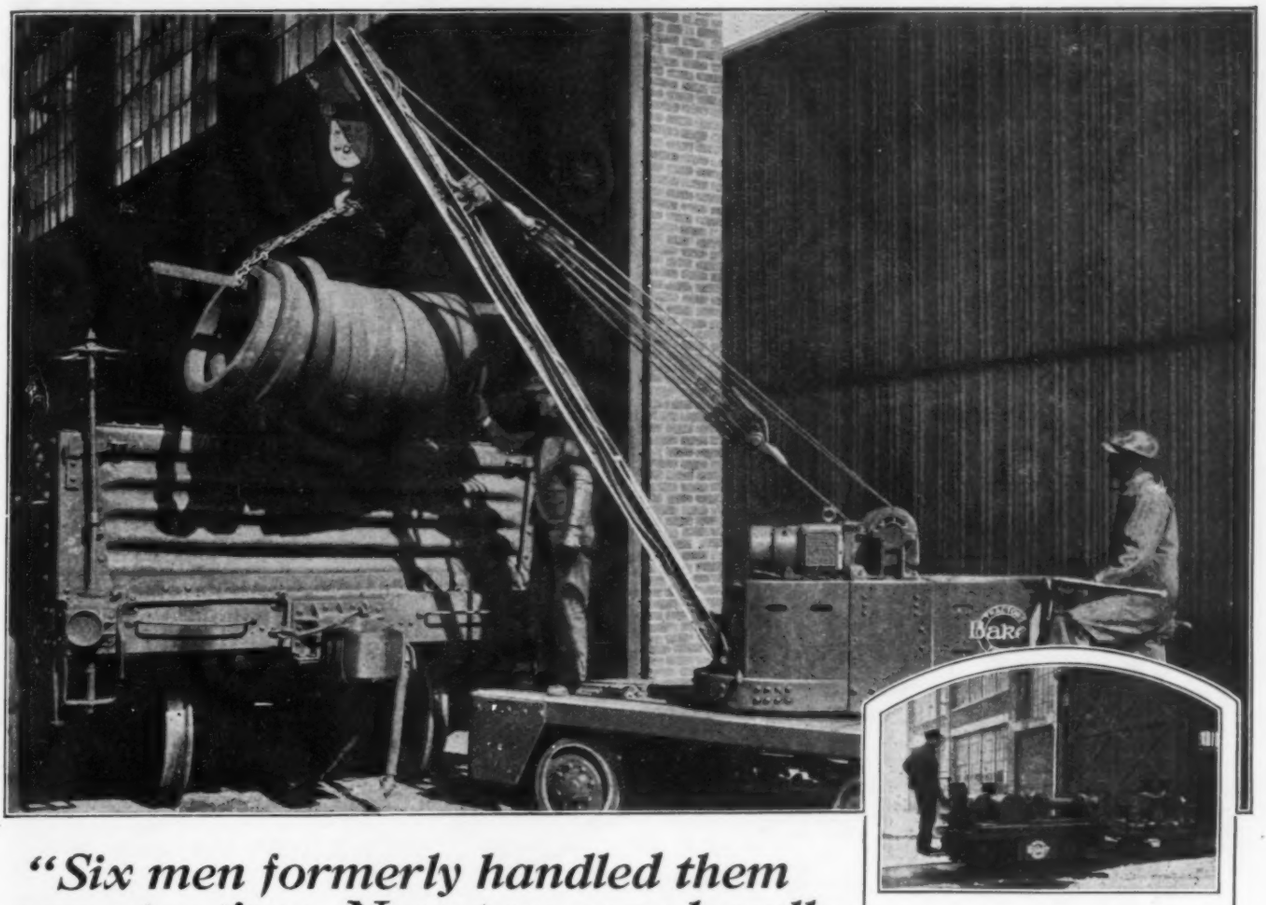
BENJAMIN PRODUCTS

Weatherproof Devices
Panel Boards & Cabinets
Punch Press Safety Devices
Screw Drivers and Tool Sets

Industrial Signals
Metal Stampings and Drawn Work
Porcelain Enameled Steel Specialties



"Six men formerly handled them one at a time. Now two men handle fifteen at once with the crane."

IT'S a great story of saving the Mead-Morrison Mfg. Co., of East Boston, tells—a saving in money, time and man power.

Take the matter of unloading gear blanks alone. When the work was done by hand, six-men were required—three on the ground and three in the car. Only one blank could be handled at a time.

With the Baker 3-way Crane, two men are all that are necessary, and they take fifteen blanks to a load, swinging them from gondola to storage with one movement of the crane. Yet this is only *one* of its many uses. The crane is in service on heavy work all day long—placing gears and shafts in the press, lifting 4300-lb. coal buckets, handling differential gears.

If you have a similar problem, it will pay you to investigate this machine. Some one of the other Baker models may serve your requirements even better.

Baker Industrial Division

THE BAKER R & L COMPANY · · CLEVELAND, OHIO

ELECTRIC TRACTORS AND TRUCKS

TRADE-MARK REG. U.S. PAT. OFF

Baker

A General Utility Truck

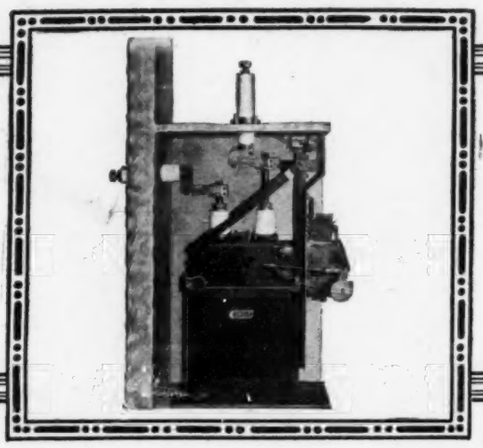
ANOTHER type of Baker is also demonstrating its worth at the Mead-Morrison plant as an all-department machine unlimited in its usefulness.

A load carrier and trailer puller as well, sufficiently husky to shove a machine tool around, and with a platform large enough to carry bulky pieces crosswise, the utility truck is in continuous demand all over the shop.

The sturdy construction of all Baker material-handling equipment insures long life and uninterrupted service under the hardest of conditions.

The Baker catalog describes all models in detail. Write for a copy today, or, better still, ask a Baker engineer to investigate your conditions and submit definite recommendations without obligation on your part.

THE BAKER R & L COMPANY
Cleveland Ohio



Self-contained operating units mounted on trucks.

Truck Type

For a replacement breaker where space is limited and a higher interrupting capacity is desired, there is nothing quite the equal of truck type oil circuit breakers.

They afford the opportunity of trebling your interrupting capacity for a given space at a low initial cost, and are usually adaptable to existing cell structure.

They require a minimum of head room and relatively small floor space. They eliminate the necessity of overhead framework and massive side walls.

—and because of their quick replacement feature offer excellent service facilities.

Don't tear down your existing cell structure—install a CONDIT truck type breaker with poles mechanically interlocked—and save money.

Get in touch with Condit

CONDIT ELECTRICAL MFG. CO.
Manufacturers of Electrical Protective Devices
South Boston, Mass.

Northern Electric Company LIMITED
Sole Distributors for the Dominion of Canada

CONDIT
Features
1. "Double" tanks.
2. Energy Absorption.
3. Self-contained mufflers.
4. Massive rigid frames.
5. Laminated contacts.
6. Truck type units.

6342

CONDIT

MIGHTY CAHOKIA

The New 400,000 H. P. Plant of the Union Electric--serving the Saint Louis District

The realization of an engineer's dream. Nothing useless—nothing wasted—nothing inefficient—nothing antiquated. Only the best that time, minds, science and money could produce—that's Cahokia—mighty Cahokia.

Material and designs were selected by trained minds. Guess work, carelessness and haphazard methods were avoided. Every item that went into the construction of this super power plant was agreed upon after thought, analyzation and experimentation. The fuses selected were BUSS renewable fuses.

Like Cahokia, BUSS fuses are the result of years of painstaking study, analyzation and experiment. BUSS fuses have successfully stood every test that the hardest kind of use could give them. Of course, they are approved by the Underwriters Laboratories, Inc.

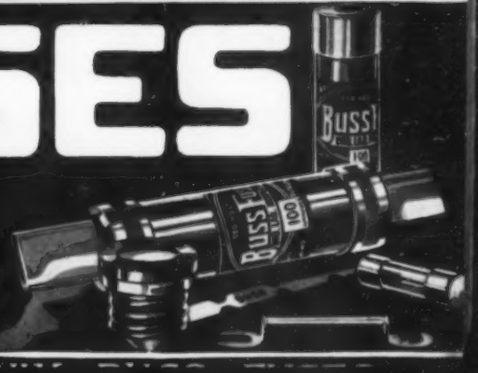
BUSS renewable fuses are simple in design. There are no small parts to be misplaced or lost. No tricky adjustments. Nothing that can be incorrectly assembled to cause poor contact.

Compare a BUSS renewable fuse with any other. Quick, easy renewal is apparent. Long life is sensed in the rugged parts designed to prevent faulty renewal of the fuse. *Fill in the coupon on the reverse side so that we may send you a sample.*

BUSS FUSES

APPROVED IN ALL TYPES AND SIZES

TRADE
BussFuses
ELECTRICITY'S SAFETY VALVE
MARK
REG. U.S. PAT. OFF.



ENDURING SERVICE REDUCES FUSE COSTS

The ability to withstand an unlimited number of blows is what gives the real saving in using BUSS renewable fuses. Long life in a renewable fuse depends on the quality and strength of material used and the design of the fuse itself.

The quality of materials used in BUSS fuses needs no discussion—the unusually heavy fibre case and the extra rugged metal parts are self-evident.

Permanency of the fuse case is assured by BUSS design. Poor contact (the greatest of all fuse destroyers) is guarded against by making faulty renewal difficult, if not impossible. Injury to the fuse case due to gaseous pressure developed on heavy blows is avoided by a design that insures positive, reliable and controlled escape of gases.

Only an examination of an actual fuse can show you the true merits of BUSS renewable fuses. Use the coupon—it is there for your convenience.

INSERT THE LINK
closed end eliminates one washer
PUT ON CAP
full length cap gives large gripping surface
SLIP WASHER ON
washer is held by bent end of link
PUT ON SECOND CAP
(note projection and recess)
and
THE FUSE IS READY FOR SERVICE

Ferrule Contact

3 to 60 Amperes

4 Parts and the Link

That's All!

Knife Blade

65 to 600 Amperes

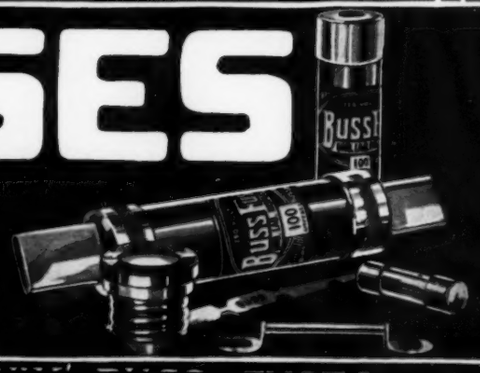
3 Parts and the Link

That's All!

BUSS FUSES

ALL ES

TRADE
BussFuses
ELECTRICITY'S SAFETY VALVE
MARK
REG. U.S. PAT. OFF



BUSSMANN MANUFACTURING CO.
2819 No. Twenty-Third St. St. Louis, Mo.
Without obligation send me for examination (check which you want)
☐ Sample 30 ampere, 250 volt Ferrule Contact Type Buss Renewable Fuse.
☐ Sample of 100 ampere, 250 volt Knife-Blade Type Buss Renewable Fuse.

Name
Company
Position
Street
City
State

IE 6-24

AIR!

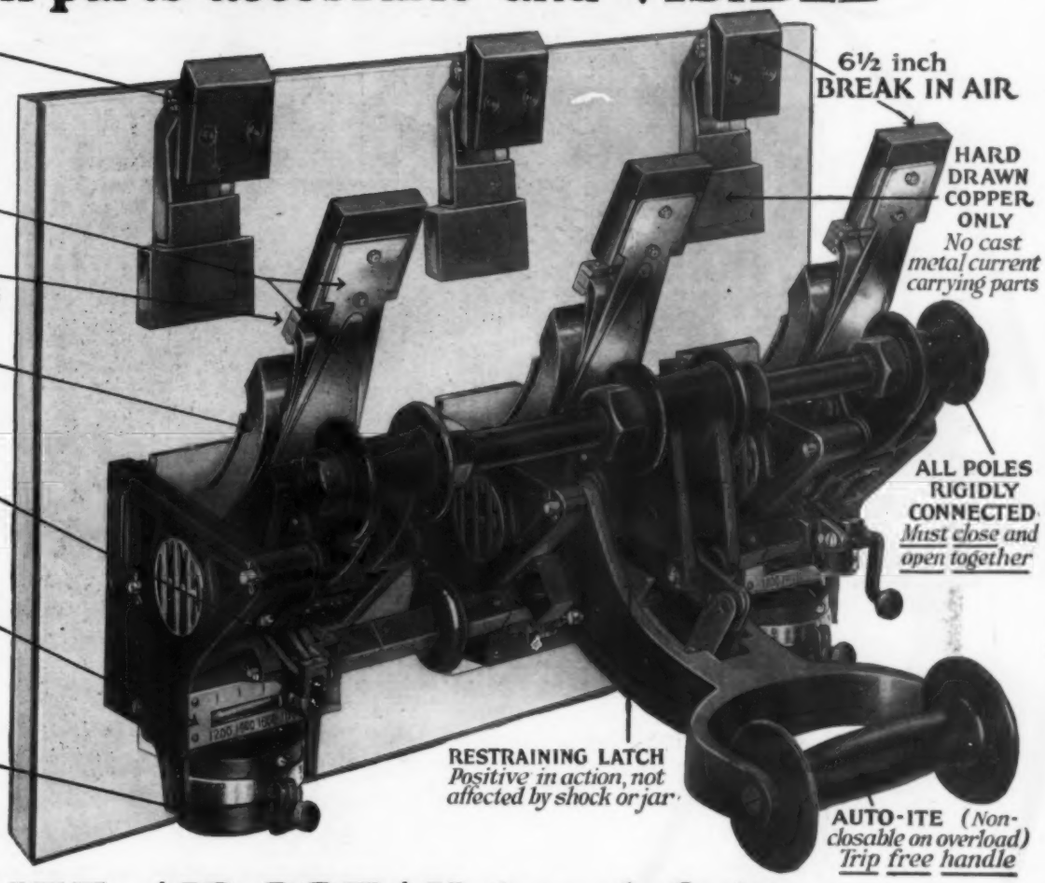
I-T-E CIRCUIT BREAKERS

For Alternating Current

600 VOLTS OR LESS

Give protection without complication

All parts accessible and VISIBLE

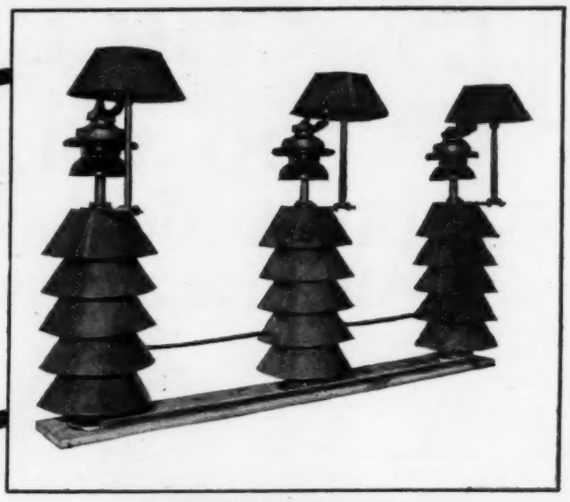

COPPER JACKETED PRESSURE CARBONS
For initial contact and final break
Mechanically strong
Electrically perfect
PHOSPHOR BRONZE CARBON SUPPORTS
HEAVY METALLIC SECONDARY BREAKING CONTACTS
LAMINATED BRIDGE
Each leaf individually formed - Heavy even pressure on every Lamination
CLOSING TOGGLES
Afford heavy contact pressure with easy closing
OVERLOAD
Direct acting. Long scale calibration. No relays or series transformers
DALITE
(Direct acting time limit) feature. Adjustable from zero to maximum time. No relays
6½ inch BREAK IN AIR
HARD DRAWN COPPER ONLY
No cast metal current carrying parts
ALL POLES RIGIDLY CONNECTED
Must close and open together
RESTRAINING LATCH
Positive in action, not affected by shock or jar
AUTO-ITE (Non-closable on overload)
Trip free handle

I-T-E AIR BREAK has definite advantages not present in the oil breaker

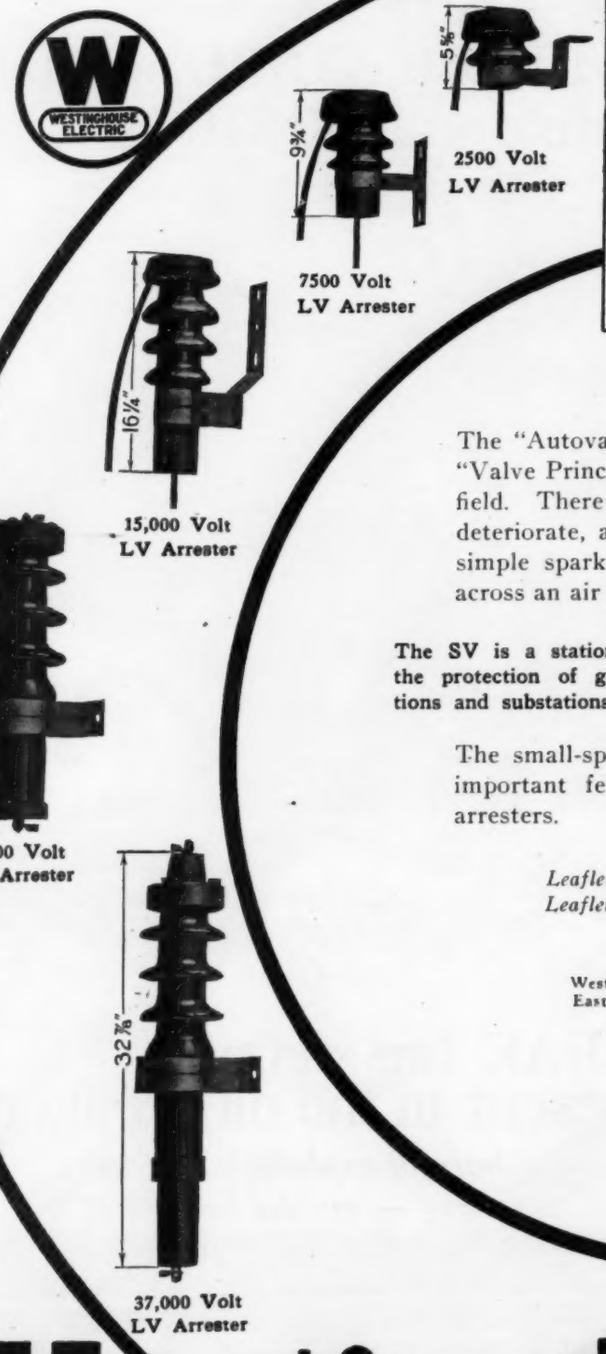
1. *No oil — to leak, carbonize, burn or explode — Just air.*
2. *No tanks to conceal anything — or the lack of it.*
3. *No cells — nothing which needs or deserves to be imprisoned — Just a faithful and efficient servant.*
4. *Inherent simplicity — with resulting low cost of installation and maintenance.*

The I-T-E CUTTER COMPANY
ESTABLISHED 1888 PHILADELPHIA

A Complete Line Of Valve Type Arresters



A 25,000 Volt, 3-Phase, Outdoor
SV Autovalve Station Arrester



2500 Volt
LV Arrester

7500 Volt
LV Arrester

15,000 Volt
LV Arrester

25,000 Volt
LV Arrester

37,000 Volt
LV Arrester

The "Autovalve" is the first arrester operating on the "Valve Principle" to cover the entire alternating-current field. There are no liquids to freeze, no chemicals to deteriorate, and no film to charge. It operates like a simple spark gap, in the form of a "glow discharge" across an air gap.

The SV is a station arrester for the protection of generating stations and substations.

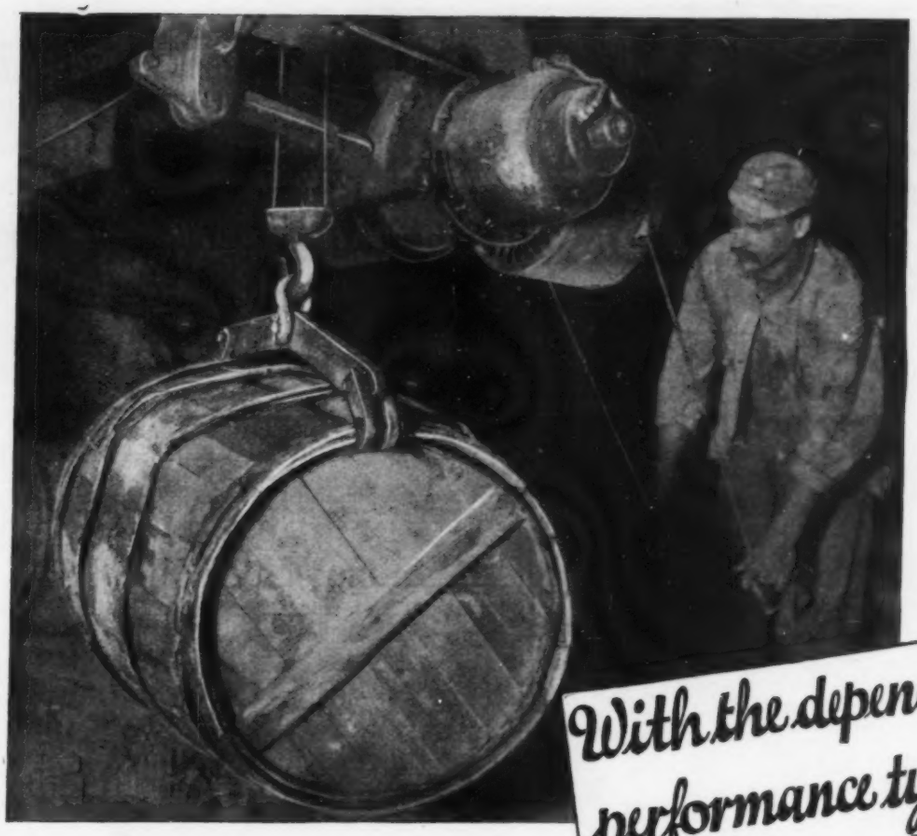
The LV is a line arrester and is now available for 2500 to 37,000 volts.

The small-space factor and mechanical advantages are important features in the popularity of this line of arresters.

Leaflet 20013-*A describes the Line Arresters.*
Leaflet 20149 *describes the Station Arresters.*

Westinghouse Electric & Manufacturing Company
East Pittsburgh Pennsylvania
Sales Offices in All Principal Cities of the
United States and Foreign Countries

Westinghouse



With the dependable performance typical of "Shepards"

For low head-room

DESIGN that makes for dependable hoisting service has not been sacrificed in providing a Shepard Electric Hoist which fully meets low head-room requirements.

Shepard hoists of this type are of the same design and thorough construction that have made "Shepards" the most widely used electric hoists in America.

20 years' hoist building experience is behind Shepard Electric Low Head-Room Hoists.

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376 Schuyler Ave., Montour Falls, N. Y.

Branches in principal cities.

Member Electric Hoist Manufacturers' Assn.

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SHEPARD

ELECTRIC CRANES & HOISTS

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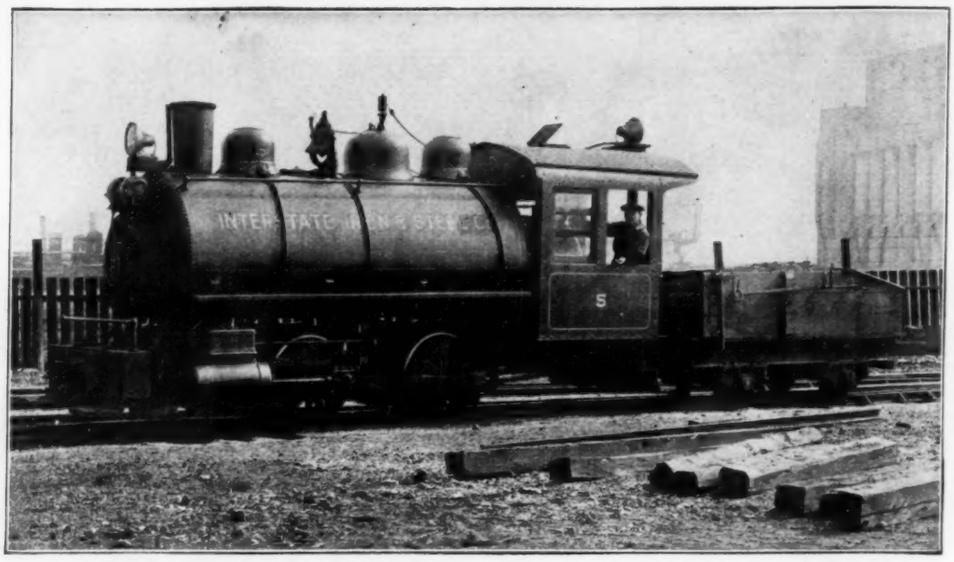
CAST ALUMINUM ALLOY BUILT TO LAST

Pyle-O-Lytes

and STEAM TURBO-GENERATORS



Interstate Iron & Steel Company locomotive equipped with Pyle-O-Lytes, Type 1045-AGB, front and rear and with Pyle-National Type K-2 Steam Turbo-Generator

Pyle-O-Lyte type 1045, widely used for yard lighting around iron and steel plants—one of many Pyle-National floodlighting units. It speeds up night work and increases the efficiency of men and equipment. Cases built of long-lived cast aluminum alloy that will outlast many ordinary sheet metal units—storm, rust and gas proof.

For Every Lighting Requirement of Iron and Steel Plants

FOR either locomotive lighting, or for yard floodlighting, you will find Pyle-National units that exactly meet your needs—efficiently, dependably, and at reasonable cost for installation and operation. The same equipment that lights 90% of the steam railway locomotives in the United States and abroad has proved its dependability for industrial lighting of every nature.

Pyle-National Steam Turbo-Generators

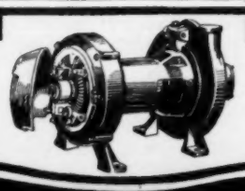
are your most dependable source of current for locomotive lighting—or for any other lighting requirement where highline current cannot be used. They are of simple but rugged construction, and long-lived, even under the most severe working conditions. Their steam consumption is less than that of any other Turbo-Generators of equal size and capacity. Furnished in five types, with capacities ranging from 500 watts to 7½ K.W.

Write for Pyle-O-Lite Catalog No. 4.

The PYLE-NATIONAL COMPANY

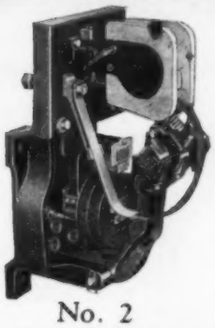
1334-58 N. KOSTNER AVE., CHICAGO

General Offices and Works:
1334-58 N. Kostner Ave.
CHICAGO

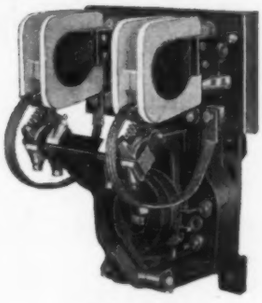


In Canada:
The Holden Co., Ltd.
Montreal, Winnipeg,
Vancouver, Toronto

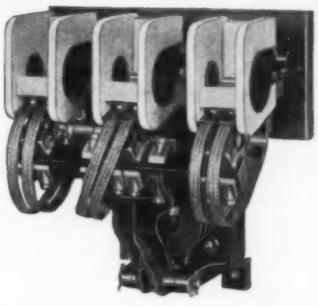
A.C.Control



No. 2
Single Pole Type ZS Shunt Contactor



No. 2
Double Pole Type ZS Shunt Contactor



No. 3
Triple Pole Type ZS Shunt Contactor

TYPE ZS CONTACTORS

The Electric Controller and Mfg. Co. is now prepared to figure on Starters and Controllers or any other special applications where simple, rugged, long-lived Alternating Current Contactors are desired.

THE ELECTRIC CONTROLLER & MFG. CO.
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BIRMINGHAM - BROWN-MARX BLDG.
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DENVER - 3535 WALNUT ST.
DETROIT - DIME BANK BLDG.
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SEATTLE - 524 1ST AVE. SOUTH
TORONTO - TRADERS BANK BLDG.

Buthee

In India the native to keep his buthee trimmed and burning must have piscatorial proclivities because he uses fish tails instead of lamp wicks.

So the fish tail becomes a part of his daily life.

The fish tale, or fish story, as we term it, is also an institution in this country.

You hear an operator say he can get Morganite life from a cheap carbon brush—that's a fish story—it can't be done.

You hear another say that he can tell by the feel of a brush whether it will work on his particular machines—another fish story.

It's only by engineering knowledge of both brush and machine that a type of brush can be accurately prescribed—so that's the way Morganites are fitted.

Speaking of tails, take note that the pigtails of Morganite brushes are inserted by a patented process. They can't work loose.

MORGANITE BRUSH CO., INC.
519 West 38th St., New York City
DISTRICT ENGINEERS AND AGENTS

Morganite

Electric Power Equipment Corp., 412-420 North 18th St., Philadelphia, Pa.

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Electrical Engineering & Mfg. Co., 909 Penn Ave., Pittsburgh, Pa.

Electrical Engineerng & Mfg. Co., 422 Union Bldg., Cleveland, Ohio.

Special Service Sales Co., 502 Delta Bldg., Los Angeles, Calif.

Special Service Sales Co., 202 Russ Bldg., San Francisco, Calif.

Electrical Engineering & Mfg. Co., 607 Mercantile Library Bldg., Cincinnati, Ohio.

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1891 — 1924

MORGAN
Construction Company
Worcester, Mass., U.S.A.

Designers and Builders of

Morgan Continuous Mills

for

Billets, Sheet Bars, Skelp, Merchant-Bars, Hot-Strip, Rods

also

Wire Drawing Machines
Producer Gas Machines
Straightening Machines
Isley Reversing Valves
Re-Heating Furnaces
Reducing Gear Units
Shears

Our Engineering Department

is prepared to solve successfully your problems in design or arrangement of plant and equipment from open hearth to finished product

1891 — 1924

NEW!

An addition to the Roller-Smith Bulletin file—just off the press—full of data on the application of small instruments to *Radio Receiving* and *Transmitting Sets* and *Broadcasting Stations*.

A new and very useful instrument is shown on page 5.

For your convenience

CLIP THIS SLIP

Request for Roller-Smith Bulletin AK-10

Name .....

Company .....

Address .....

City ..... State .....

ESTABLISHED 1895

RUMSEY ELECTRIC COMPANY

ELECTRIC SUPPLIES and MACHINERY

1007 Arch St., PHILADELPHIA

FACTORY DIRECT REPRESENTATIVES

EFFICIENT
RELIABLE
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HIGH TENSION
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INSULATORS

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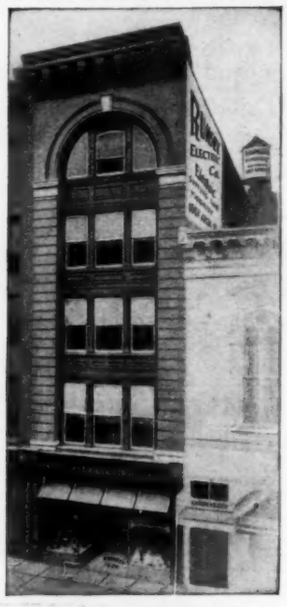
TRANSFORMERS



STORE AND OFFICE BUILDING
WAREHOUSE, 1010 CHERRY ST.

SANGAMO

METERS

BUILT LIKE A WATCH

"Sirocco"

AMERICAN BLOWER CO.
VENTILATING FANS
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C-H

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DEVICES

UNITED STATES
ELECTRIC TOOLS

Pittsburgh Transformer Company

Largest Manufacturers of Transformers Exclusively in the United States

Pittsburgh, Pennsylvania

ALLIANCE CRANES

Largest Builders of the World's Largest Cranes

204 of 100 Tons Capacity and Over

STANDARD CRANES

55	100 tons
2	115 tons
42	125 tons
24	150 tons
22	175 tons
2	200 tons
1	225 tons
1	250 tons
3	430 tons

STRIPPING CRANES

8	100 tons
1	125 tons
19	150 tons
13	200 tons
1	Single Ram, 320 tons

COMBINATION CHARGERS AND STRIPPERS

3	100 tons
3	150 tons
4	200 tons

W. E. finish Salamander magnet wire is particularly adapted for rewinding field and armature coils, solenoids, etc., and is used extensively in the steel industry. It is acid-proof, moisture-proof, oil-proof, heat-resisting and has an extremely tough, smooth, hard finish.

For further information write to our nearest representative for Salamander wires and cables—

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Chicago, Ill. . . . . J. D. A. Cross, 213 S. Peoria Street
Cleveland, Ohio . . . H. Lee Reynolds Company, 309 Plymouth Building
Denver, Colo. . . . . Franklin Sales Company, Denham Building.
Los Angeles, Cal. . . A. S. Lindstrom, 1144 Maple Avenue
Philadelphia, Pa. . . . . F. K. Simons Electric Co., Fuller Building
Pittsburgh, Pa. . . . . H. Lee Reynolds Company, Oliver Building.
Portland, Ore. . . . . A. S. Lindstrom, 312 McKay Building
Salt Lake City, Utah . . Raymond Ackerman, 419 Dooly Building
San Francisco, Cal. . . . A. S. Lindstrom, 111 New Montgomery Street
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YORK INSULATED WIRE WORKS

of General Electric Company

Works: York, Pa. Office: 1737 Broadway, N. Y. C.

All Service—
No Frills or Tricks!

You don't want a plaything when you buy fuses. You're not hunting untried trick inventions. Special deals don't interest you. What you are after is the best fuse that money can buy—and you certainly get just that in Trico Fuses—at no greater cost.

Although all fuses look alike on the outside there is a great difference in the inside design and construction which determines the efficiency of the fuse itself.

Each Trico Renewable Element is composed of a fusible link surrounded by a finely divided arc-choking powder, encased in a kraft container which is virtually a fuse within itself.

This powder-packed element makes the Trico Renewable Fuse more efficient than any other kind because the fuse link is supported and kept in shape when heated during momentary overloads, preventing premature "blowing" and consequent expensive shutdowns.

You cannot char the fibre casing as the powder-packing chokes the flash of the melting fuse link preventing pitting of metal terminals or blades, eliminating blackening and heating of contacts so that the Trico Fuse is the easiest to renew.

Trico Renewable Fuses are made in all standard sizes in 250 and 600 volts, and are fully approved by Underwriters Laboratories.

The best proof of all is your actual use of Trico Renewable Fuses—the one way to get the truth about their performance. Then you will know that TRICO "Power-Packed Time-Limit" renewal elements eliminate unnecessary blows and insure perfect satisfaction.

Write for address of nearest Sales Office.

TRICO FUSE MFG. CO.
MILWAUKEE, WIS.

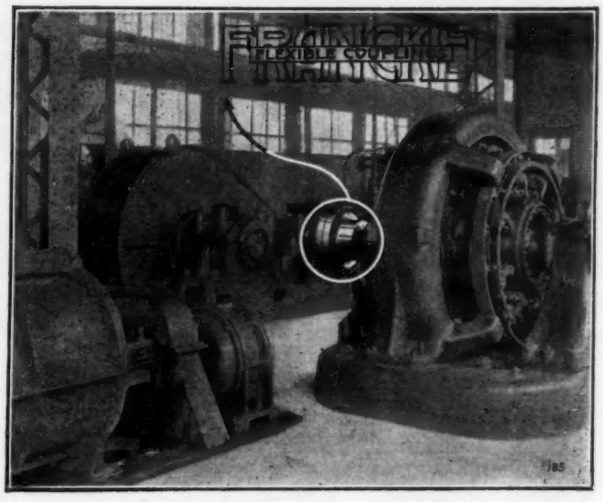
The TRICO Powder-Packed Plug Fuse

Have you tried it?

TRICO FUSES
REG. U. S. PAT. OFF.
Renewable Cartridge

FRANCKE
FLEXIBLE COUPLINGS

"They make good machines last longer"



If you are one of the many satisfied users of Francke Flexible Couplings perhaps you know the service we have been trying to render for more than twelve years—

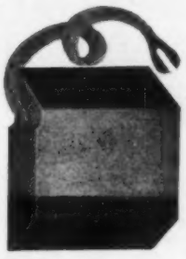
If one of our more than 37,000 Francke Flexible Couplings has failed to give you entire satisfaction please tell us about it so we can make good—

Five distant types of Francke Flexible Couplings have been developed in more than sixty individual sizes, to transmit from ¼ H.P. to 8,700 H.P., to operate at low speed or at high speed, and for any shaft sizes.

The service we try to render is to deliver to you—when you need it—a Francke Flexible Coupling that will meet any reasonable operating conditions at the lowest possible purchase price consistent with low maintenance cost.

Our Bulletin No. 37 tells quite a little about Francke Flexible Couplings. May we send you a copy?

SMITH & SERRELL
Coupling Specialists Since 1912.
47 Central Avenue, Newark, N. J.
District Office, Fulton Building, Pittsburgh



5 Reasons
Why USG Brushes
are
Extraordinary Brushes

1. Because the graphite used in their make-up all comes from our own mines in Mexico.
2. Because every step in the manufacturing process, from mining the ore to the finished brush, is done by our company.
3. Because our engineers are Brush Experts who have devoted their lives to the perfection and manufacture of better brushes.
4. Because each order is considered separately and the individual requirements of the machine taken into consideration before the grade recommendation is made.
5. Because of the feeling of ease and security which follows the application of U. S. G. Brushes.

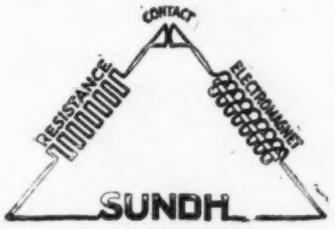
USG

on every brush

Write for the list and characteristics of all grades of U. S. G. Brushes.

THE UNITED STATES GRAPHITE COMPANY

Saginaw, Michigan, U. S. A.



Steel Men!

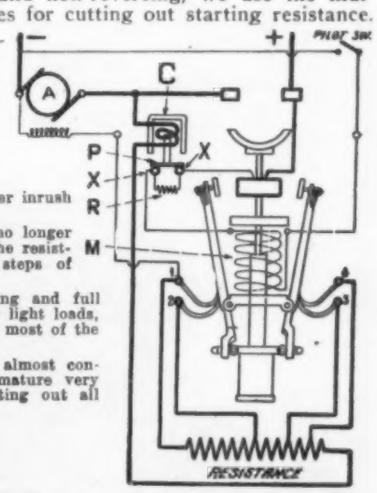
Isn't this what some of you wanted, as brought out in your discussion of control in your Journal of November, 1921? A control that would have definite time limit modified with current limiting element?

You want a starter to obey its real function, don't you? i. e., to start and accelerate a motor by cutting in resistance, then out, in the shortest possible time in relation to the load. You want the motor to "mote" if it's at all possible to do so, whether the voltage is high or low, or whether there is excessive friction on a cold Monday morning. If the first current inrush does not start it, the next one may. If we can't get it to start on small amounts of current, we want to provide automatic means of increasing the current or power so that it will start, provided that no one has placed a crowbar in between the gears or there happens to be a short circuit. In that case, overload circuit opening devices take care of the condition.

We have been using this method since 1911. On large size motor starters, reversing and non-reversing, we use the multiple level starter as a pilot relay whose multi-contact energizes large shunt wound switches for cutting out starting resistance.

The action of this control is easily understood from the diagram, and the following description of operation:

The relay C is in series with the armature only during the starting period and is normally set to operate at about 130% of normal current. When the current in the armature of the motor equals or exceeds this setting on the starting inrushes, the armature of the relay lifts the plate P from the two contacts XX and by this action inserts the resistance R in series with the solenoid coil M of the automatic starter. The resistance R can be made to have a resistance so that when inserted in the circuit of the coil M (by action of excess load on the armature of motor at start) it partly destroys the effective magnetic pull of coil M and prevents the cutting out of any more resistance in the armature circuit, but at the same time there is sufficient magnetic pull to lift the core very slowly so that in time, even with the insertion of this resistance in the magnet coil circuit, the next succeeding step of resistance will be cut out, giving a larger inrush current to the motor.



Under normal conditions as soon as the current in the armature reduces to about normal, the coil C can no longer hold up plate P and it consequently drops, thus closing the circuit across contacts XX, and short circuiting the resistance R, allowing coil M to be again fully energized and to act with full power, thus cutting out succeeding steps of resistance quickly.

The retarding action caused by excess load on coil M may take place during any interval between starting and full running position. The time of the dash pot is generally set for a minimum of 1½ seconds, which in case of very light loads, the cutting out of resistance would take approximately this time, since the series relay coil C plate XX, would be most of the time short circuiting the resistance R.

Under abnormal, extremely heavy loads, where the series coil C would lift its armature and hold it up almost continuously, thus inserting all the resistance in the coil, R circuit on automatic starter coil M would lift its armature very slowly against the action of the dash pot and light pulling force, and may take up to 15 seconds before cutting out all resistance.

The resistance R may be made of a value as to either increase or decrease the pull of magnet coil M.

Write for Catalog.

SUNDH ELECTRIC COMPANY Newark, N. J., U. S. A.

CROCKER-WHEELER

PIONEER MOTOR MANUFACTURERS
Established 1888

May 17, 1860
A milestone in electrical history

1860—a year of great moment for the world and industry: Planté—and the lead storage battery; Reis—and the telephone.

And on May 17, 1860, Schuyler Skaats Wheeler was born—engineer, manufacturer, author, inventor. To the brilliant mind and almost tireless energy of this electrical pioneer, can be traced a score of outstanding developments.

Among the many inventions of Dr. Wheeler may be named the electric fire engine, series-multiple motor control, and the paralleling of dynamos. In 1904, he received the John Scott medal of the Franklin Institute for inventing the electric fan.

For the important role it has played in the electric motor industry, the Crocker-Wheeler Company is immeasurably indebted to the genius of this remarkable man,—one of its founders and, until his death on April 20, 1923, its president.

CROCKER-WHEELER COMPANY
AMPERE NEW JERSEY

BALTIMORE	CHICAGO	NEW YORK
BIRMINGHAM	CLEVELAND	PHILADELPHIA
BOSTON	DETROIT	PITTSBURGH
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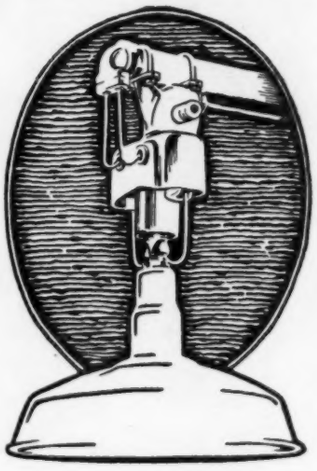
Foreign Distributor: International Western Electric Co.

MOTORS & GENERATORS

THOMPSON
Safety DISCONNECTING Hangers



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Lamp Maintenance

Accessible

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Ease and Safety

for both indoor and outdoor use—easily included in present lighting systems.

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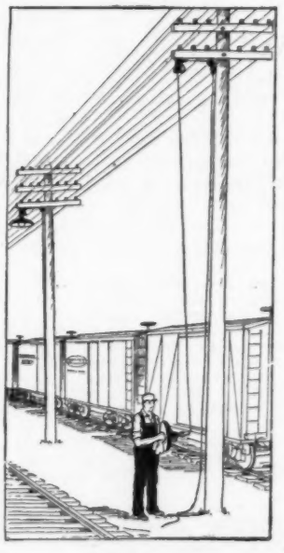


The Thompson Electric Co.

226 St. Clair Avenue, N. E.
Cleveland, Ohio, U. S. A.

Wayman

Where Economy and Permanency Meet!

Type E—Conduit Hanger

Labor saved, time saved—these, unquestionably, are a few of the ingredients of true economy. But where there is no permanency, there can be no **real** economy. Rugged and sturdy, durable and lasting, whether for continual service or temporary work, Wayman products bring the intense satisfaction of a job well done.

Regard two notable instances of Wayman devices; the Adjustable Insulator Support No. 200 on the right—with single wire cleat fitting; and the Type E Conduit Hanger—on the left. No bolts or screws; carries in any direction.

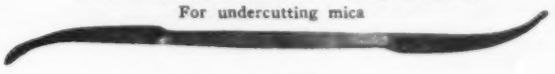
Adjustable Insulater Support, No. 200

Write for our Illustrated Catalog No. 3 today.

Wayman Electric & Mfg. Co.
East Palestine, Ohio

Use "Imperial" Commutator Stones

COMMUTATOR SLOTTING FILES
For undercutting mica



GOODNITE CLEANING TOOL
For cleaning Commutator slots

REASON NO. 4. They remove ridges, flat spots, high bars, high mica, quicker and more effectively than any other method. Write for bulletin giving complete information.

(*Advantage No. 5 will be given next month.*) 2628 users on May 1st. A gain of 137 for April.

Send the Coupon for Complete Information

We can supply you with

Commutator Grinders
Slotting Files
Slotting Machines
Commutator Cement
Insulating Beads
Insulating Varnish
Gauze Wire Brushes
Portable Blowers

THE MARTINDALE ELECTRIC CO.,
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Gentlemen: Please send me information about your products.

Name and Title.....
(Please print)

Company .....

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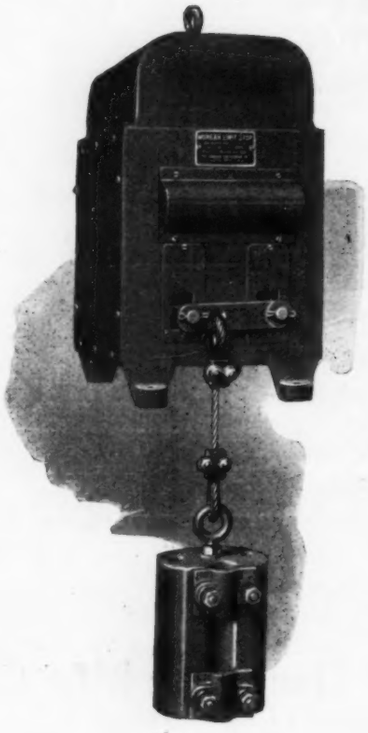


Morgan Safety Limit Stop

WACKERLY TYPE

For All Types of Direct Current Motors

A FEW OF THE ADVANTAGES

No heavy current broken by contactors.

Limit Stop can be connected up with any standard make of controller.

No extra conductors required.

Normal lowering circuits established immediately upon reversal of controller. No waiting to lower through resistance.

No external banks of resistance. Limit Stop is self contained.

Only one swinging weight used, this being guided by one of the hoisting ropes.

Positive in action. A movement upward of weight of a fraction of an inch will actuate limit stop.

Occupies minimum floor space on trolley.

Sequence of operation of contactors obtained by simple system of levers. No cams, springs or counterweights used.

For full particulars on this stop send for Bulletin No. 29.

The Morgan Engineering Co.

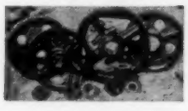
Alliance, Ohio

CHICAGO
122 So. Michigan Ave.

NEW YORK
120 Broadway

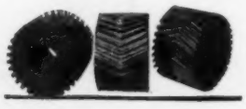
PITTSBURGH
1420 Oliver Bldg.

Herringbone Mill Pinions



Motor and Crane Gears

Mill Table Gears

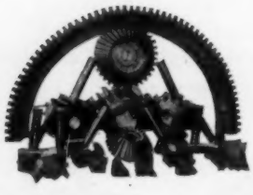


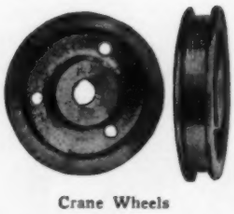
Herringbone Gears

Tool Steel Face
as hard here as on the very surface (This is one of the great differences between tool steel and case-hardening methods)
Toughened Center

Cincinnati "Tool Steel" gears outlast 8 to 10 Untreated and are much stronger

Spindles

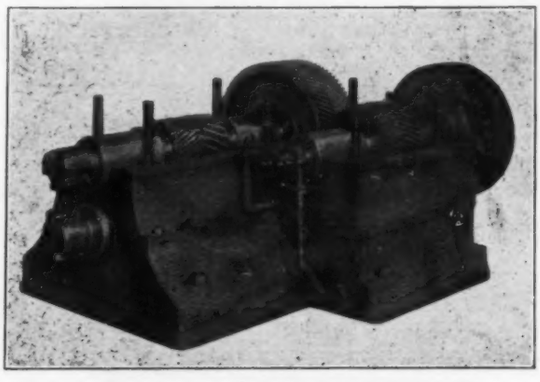




Crane Wheels

The Tool Steel Gear and Pinion Company

CINCINNATI, OHIO



Fawcus Combination Herringbone Gear Reduction and Pinion Housing

This reduction is for driving a single stand 11″ finishing mill for a large southern steel maker.

This reduction is a recent development. The design confines in a single unit the transmission of power from the motor to the mill. The base plate of the pinion housing and gear reduction are cast solid, thus vibration is practically eliminated, and as a result wear, tear and maintenance costs are reduced to an absolute minimum. The saving of space and cost is apparent over separate pinion housing and gear reduction.

This gear reduction is part of a contract on which we furnished the largest Tandem Herringbone Gear Drive ever built for driving a 6 stand 16″ continuous bar mill, also one Tandem Drive for driving 4 stand 12″ continuous mill. All gear drives furnished with Fawcus Flexible Couplings for motor connections and Fawcus Universal and Fawcus Crab Thrust Collar Couplings for the mill connections.

Fawcus Machine Co.

PITTSBURGH, PA.

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Steinbart Patent Pressure Burners

offer an investment of 200% and better to every blast furnace or steel works. If you want to know more about them ask any of our customers.

Steinbart Burners are in operation or under construction at the following plants:

National Tube Company	Lorain, Ohio	All Stoves
" " "	" "	6—1300-hp. Boilers
" " "	McKeesport, Pa.	7 Stoves
" " "	Wheeling, W. Va.	Boilers
Wheeling Steel Corp.	Steubenville, Ohio—1st order	4 Boilers
" " "	" " 2nd "	7 "
" " "	" " 3rd "	1 Boiler
" " "	" " 4th "	8 Stoves
Bethlehem Steel Company	1st order—Sparrows Point, Md.	2 Boilers
" " "	2nd " Lackawanna, N. Y.	2 "
" " "	3rd " " "	8 "
" " "	4th " Johnstown, Pa.	4 Stoves
Trumbull-Cliffs Furnace Company	Warren, Ohio—1st order	4 Boilers
" " " "	" " 2nd "	3 Stoves
Shenango Furnace Company	Sharpsville, Pa.—1st order	4 "
" " "	" " 2nd "	4 "
Otis Steel Company	Cleveland, Ohio	4 "
Steel Company of Canada	Hamilton, Canada	6 Boilers

For particulars apply to the American Heat Economy Bureau, Inc., 926 Wabash Building, Pittsburgh, Pa.

Electrical Engineering and Manufacturing Company

General Offices:

PITTSBURGH, PA.

We are prepared to furnish your requirements in the following materials and equipment:

"MORGANITE" Carbon-Graphite Metal Brushes.

"ROWAN" Automatic Controllers and Starters.

"SUMET" Bronze and Babbitt Bearing Metals.

"DUTCHESS", Empire or Varnished Cloth and Tape.

"SCHENECTADY" Electrical Insulating Varnishes and Compounds.

"BELL" Cedar Poles.

CROSSARMS: Douglas Fir and Pine.

LINE MATERIALS: Hangers, Brackets, etc.

TRACK GRINDERS: Reciprocating, Rotating, and Swing Frame.

"AJAX" Resistance Type Welding and Bonding Machines.

"LITEWELD" Electric Arc Welder—Dynamotor Type.

RAILWAY and Mine Bonds.

MINE HOISTS and Winches, Car Pullers, etc.

HIGH and **LOW** Tension Insulators.

"ELPECO" High and Low Tension Switching Equipment, Bus Fittings, etc.

"BENNETT" Lightning Arrestors.

We have a corps of expert engineers, specialists in the above lines, who will be glad to give immediate attention to your inquiries or to see you at your request for consultation regarding applications or equipment. Call or write our nearest office.

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Phone Maine 3257

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907-909 Penn Ave.
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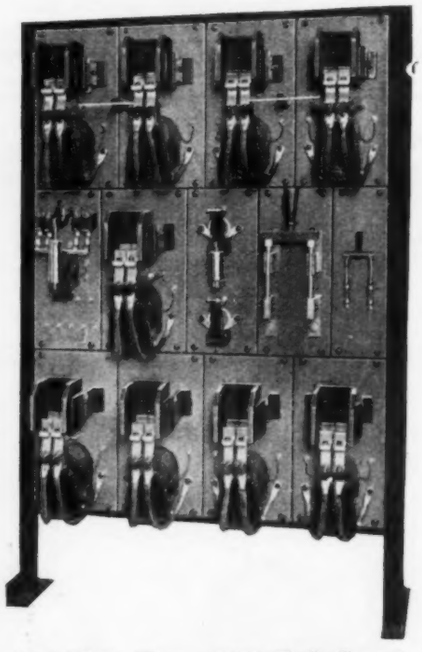
Automatic Motor Starters and Controllers

FOR

Alternating and Direct Current Electric Motors

May we send our nearest representative to see you?

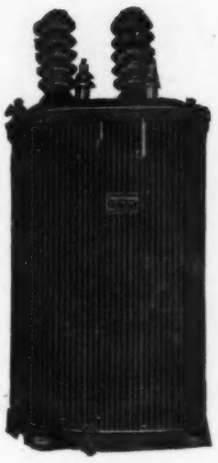


150 H.P. Type 4750 Full Speed Reversing Mill Controller

ROWAN CONTROL

THE ROWAN CONTROLLER CO., BALTIMORE, MD.

MOLONEY
TRANSFORMERS



WE have been manufacturing transformers now for over a quarter of a century—a long time in an industry so young.

Moloney Engineering Experience has dealt with the transformer in every phase of its development.

From the first, Moloney Engineers have been animated by a two-fold purpose: to build the highest attainable quality, and to build it economically.

Moloney Transformers are recognized by all transformer users as the highest standard—a fact which demonstrates the success which has crowned the efforts of Moloney Engineers.

MOLONEY ELECTRIC CO.
Manufacturers of Transformers Exclusively
FACTORY AND MAIN OFFICE
St. Louis, Mo.
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LAPP HIGH VOLTAGE PORCELAIN

Did you ever hear of a failure of a Lapp Insulator?

Seven years of production—including highest voltage pin and suspension types —without a failure!

There is the reason for use of Lapp Insulators, besides which—for "trimmings" —they provide unexcelled mechanical strength.

Lapp vacuum process of porcelain production, surfaces of porcelain glazed all over, Lapp over potential test methods.

LAPP INSULATOR CO., Inc., LeRoy, N. Y.

S. H. LANYON
509 New Call Bldg., San Francisco

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Strength

is first and foremost of all considerations entering into the construction of

'UNION'

RENEWABLE FUSES

No other fuse is built so ruggedly. No other can be renewed so quickly. That explains why no other fuse withstands so many blowouts and why the

"UNION" Saves More than ANY Other Renewable Fuse

At Leading Dealers and Jobbers

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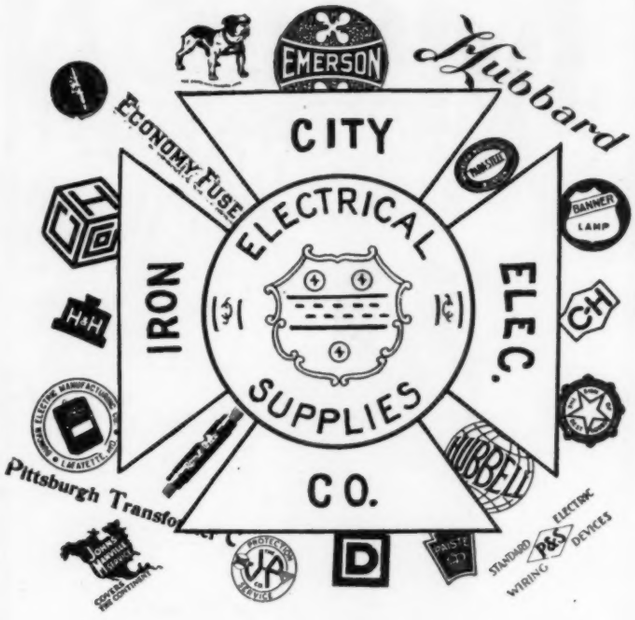
CHICAGO FUSE MFG. COMPANY

Manufacturers also of Switch and Outlet Boxes, Cut-Out Bases, Fuse Plugs Fuse Wire and Automobile Fuses.

CHICAGO
NEW YORK



The Trade Mark

of the

Iron City Electric Co.

436-38 Seventh Avenue

Pittsburgh, Pa.

REPRESENTING

"The House That Service Built"

IS BACKED BY A GROUP OF

TRADE MARKS

of Well Known Manufacturers Guaranteeing the Quality of the Goods You Receive

SAND—

is the only Cure for

SLIPPERY CRANE RUNWAYS

"It Takes Sand To Win"

Do you allow your men to pour it on with a bucket?——

Or do you allow your cranes to be operated on slippery runways?

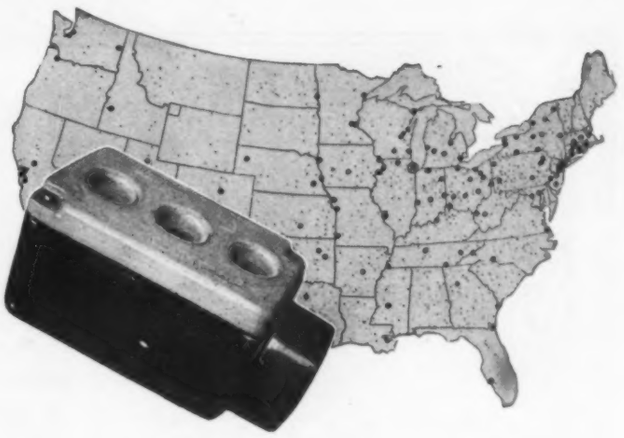
Both methods endanger your cranes, the lives of your operators and the men on the floor.—This also means unnecessary delays and losses.

Apply sand at the right time, the right place and in the proper amount by equipping your cranes with Lintern Electro Magnetic Sanders.

A number of plants are now in the process of equipping all of their cranes with Sanders. They will secure efficient and economical operation with all hazards due to slippery rails eliminated.

The
NICHOLS-LINTERN COMPANY

7960 Lorain Avenue Cleveland, Ohio



This Perfect Distribution Is Another Reason for Standardizing on Unilets

Appleton's "Unilet" service is nationwide. Jobbers in 118 cities from coast to coast have "Unilet" stocks ready to assist in the most difficult wiring installations.

This wide distribution makes quick deliveries certain and permits you to standardize on Unilets for all wiring work without fear of disappointment at some critical time.

Furthermore, standardizing on "Unilets" means better jobs done in less time, because helpers, specializing in the handling of Unilets, can work faster and more efficiently than they can when other lines are used intermittently.

Unilets are pressed from cold steel—they are strong, light in weight, true, and smoothly finished. And there is one for every wiring need.

Write for Appleton Catalogue 9-T
It is a dependable guide to better wiring.

APPLETON ELECTRIC COMPANY
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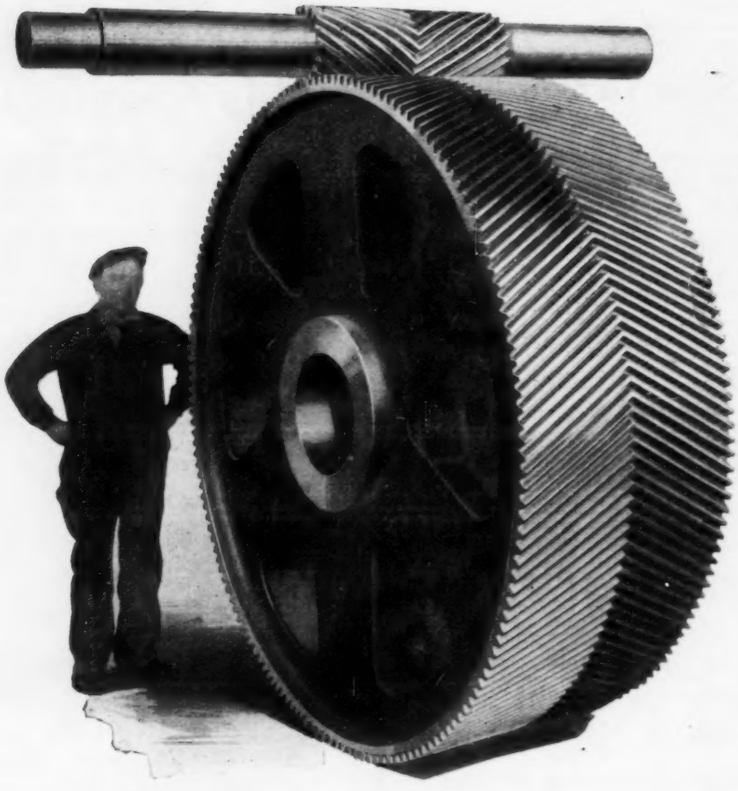
Don't Bother With Laborious Specifications

Just Write In

"SYKES GEARS"



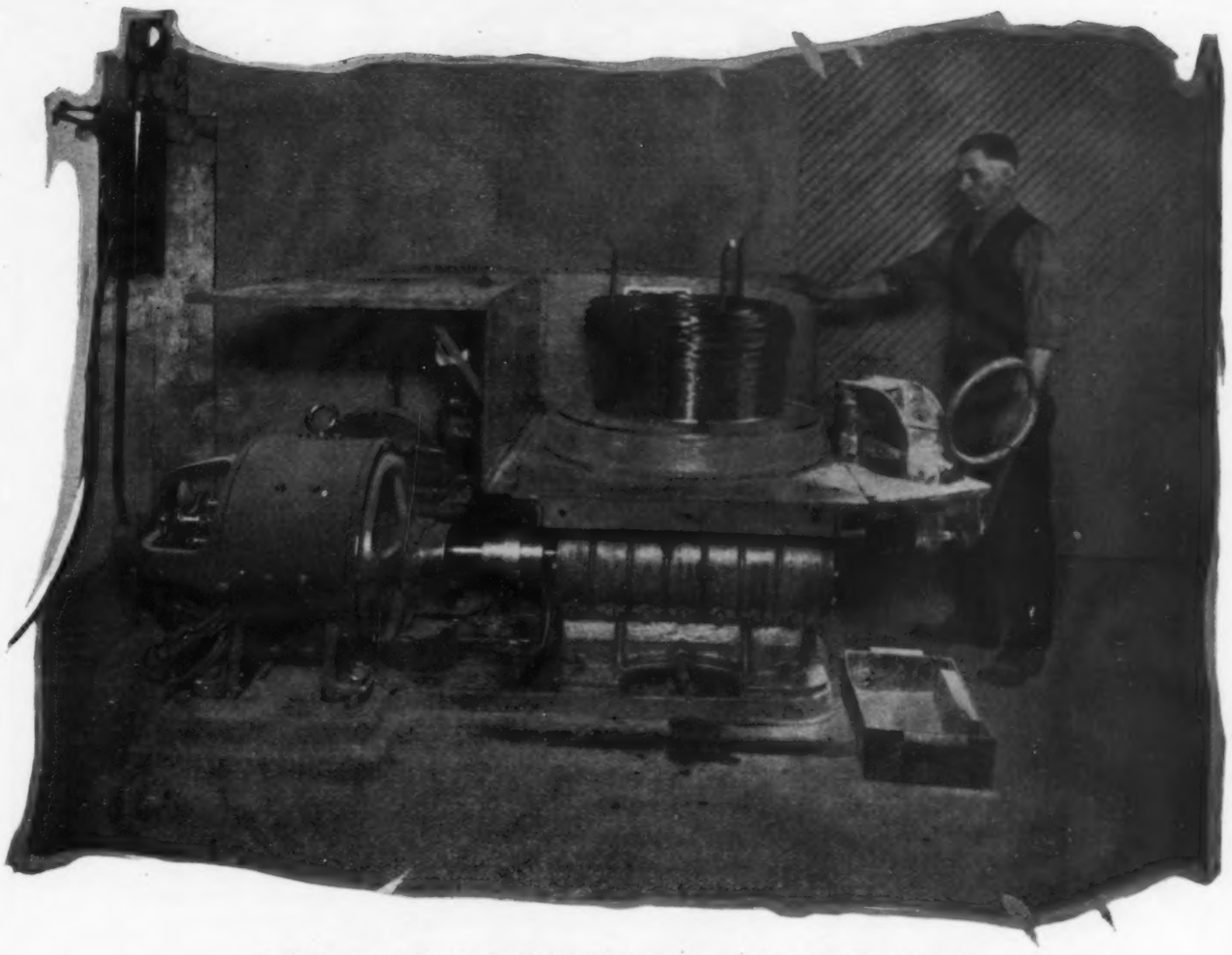
The Herringbone Gear

WITH A BACKBONE

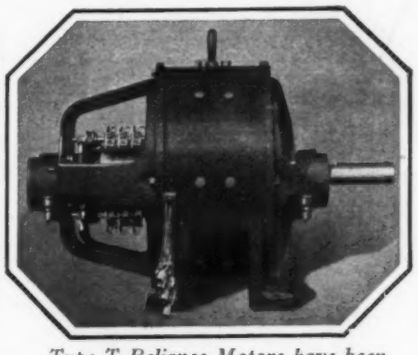
GENERATED FROM THE SOLID—CONTINUOUS TEETH—SHARP APICES

FARREL FOUNDRY & MACHINE CO., Inc.

BUFFALO, N. Y., U. S. A.



Individual wire block made by Vaughn Machinery Company driven by adjustable speed Type T Heavy Duty Reliance Motor



Type T Reliance Motors have been giving dependable service and helping to increase production in the iron and steel industry for over eight years. No change affecting interchangeability has ever been made.

Helping to draw wire faster

This individual wire block means greater production with better control of quality and greater safety. Four important advantages are contributed by the Type T Reliance Motor and special control equipment.

Adjustable driving speeds mean maximum drawing speeds to suit physical properties of wire and quality desired.

Very slow pulling-in speeds.

A positive, easily operated electrical safety device.

A rugged and dependable drive that will withstand hard service.

Bulletin 2014 will show you in detail how Type T Motors are built to meet the ideas of steel mill electrical engineers.

Reliance Electric & Engineering Company

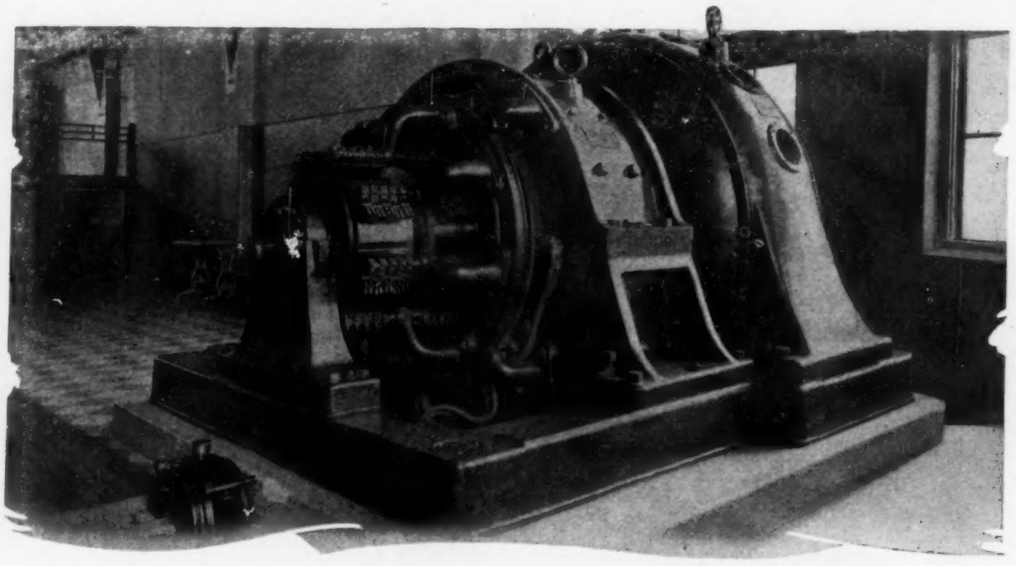
1080 Ivanhoe Road, Cleveland, O.

Branches: Boston, New York, Philadelphia, Pittsburgh, Cincinnati, Detroit, Chicago Birmingham, Ala.

Type T Heavy Duty RELIANCE MOTORS

Direct Current

SKF



750 K. W. Motor Generator Runs

Silently and Efficiently on Self-Aligning Ball Bearings

DAY in and day out, this 750 K. W. motor-generator delivers its power unfailingly and silently. The efficiency and dependability of this giant machine has been made possible by Skayef Self-Aligning Ball Bearings. No power is lost in overcoming friction of plain bearings. No time is lost in costly shutdowns to make bearing adjustments or renewals.

Users of hundreds of thousands of motors and generators have found that the two chief causes of trouble—wear of plain bearings and leakage of oil onto windings—are eliminated by Skayef Self-Aligning Ball Bearings. True spheres of steel—accurate to within 1/2 of 1/10,000 of an inch—roll in races of hardened steel and maintain precise, original settings. Oil tight housings prevent leakage of lubricant on windings and coils and eliminate consequent troubles.

Our engineers will gladly help you realize the economies and advantages of ball bearings on your electrical equipment.

THE SKAYEF BALL BEARING COMPANY

Supervised by SKF INDUSTRIES, INC., 165 Broadway, New York City

1166

Normal View *Deflected View*

Cutler-Hammer Magnet Construction Permits Use of Proper Steels

Low carbon steel—high permeability.

Tough high carbon steel for withstanding the blows.

THERE is no compromise in selecting the steels used in Cutler-Hammer Lifting Magnets.

For the case, low carbon steel with high permeability is used. The ring being separate—and subjected to greatest abuse—is made of a higher carbon steel with the correct percentage of manganese.

The low carbon steel is best for the case—the higher carbon steel, best for the ring. Since these parts are made separately, we are free to select each for its part.

And in addition—the ring is readily replaceable.

Bottom view of C-H "Red" Magnet showing heavy outer and central pole shoes, and the strengthening ribs on the manganese coil shield.

THE CUTLER-HAMMER MFG. CO.

Magnet and Clutch Department

Works: MILWAUKEE *and* NEW YORK

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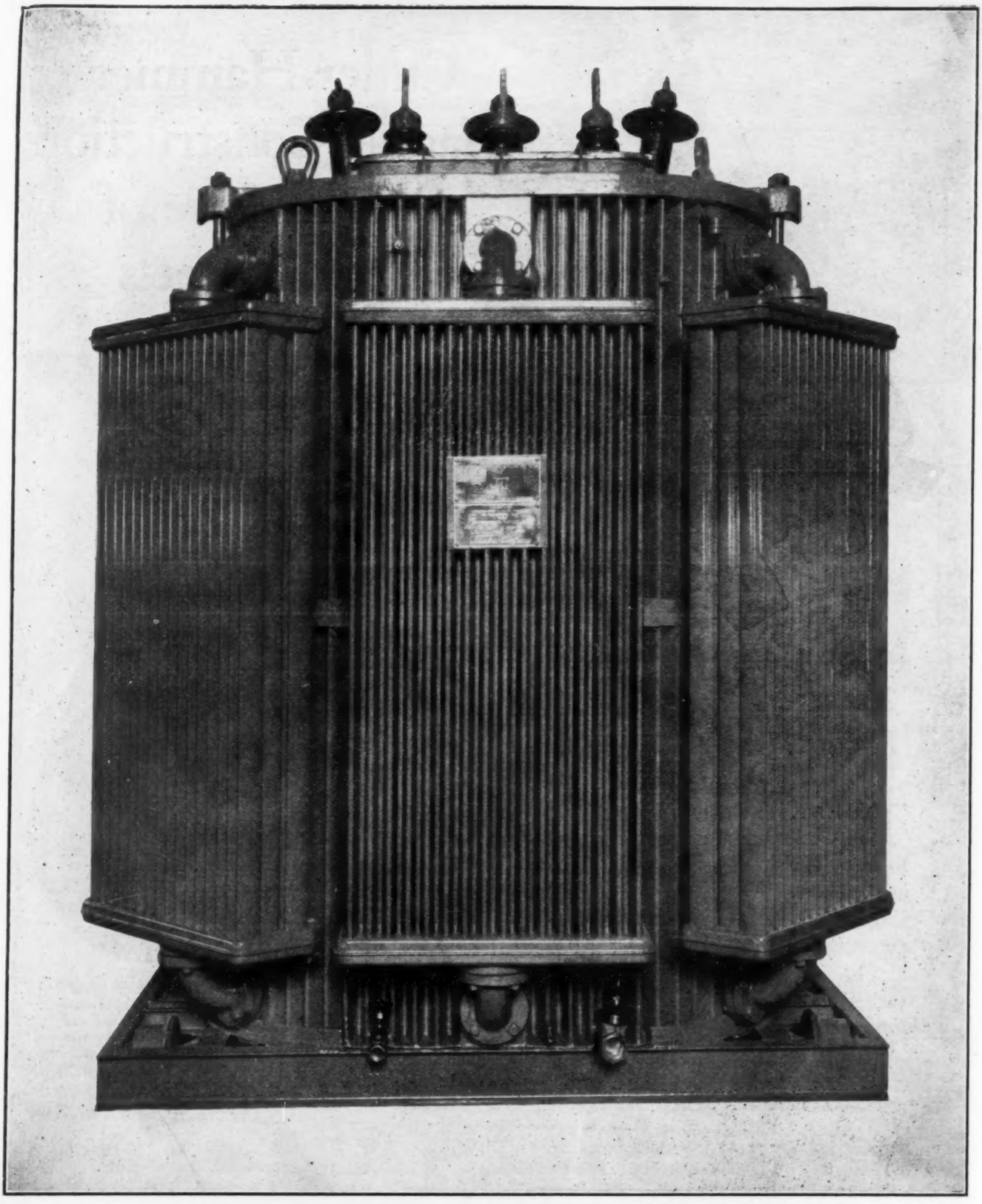
C-H CUTLER-HAMMER

LIFTING MAGNETS



Packard Transformers are as good as they look. Write for complete data and prices.

The Packard Electric Company
WARREN, OHIO

The

U-RE-LI-T-E

is so much better than
a fused switch that it
is in a class by itself.

Handbook just off the press—Send for it.

The Cutter Company
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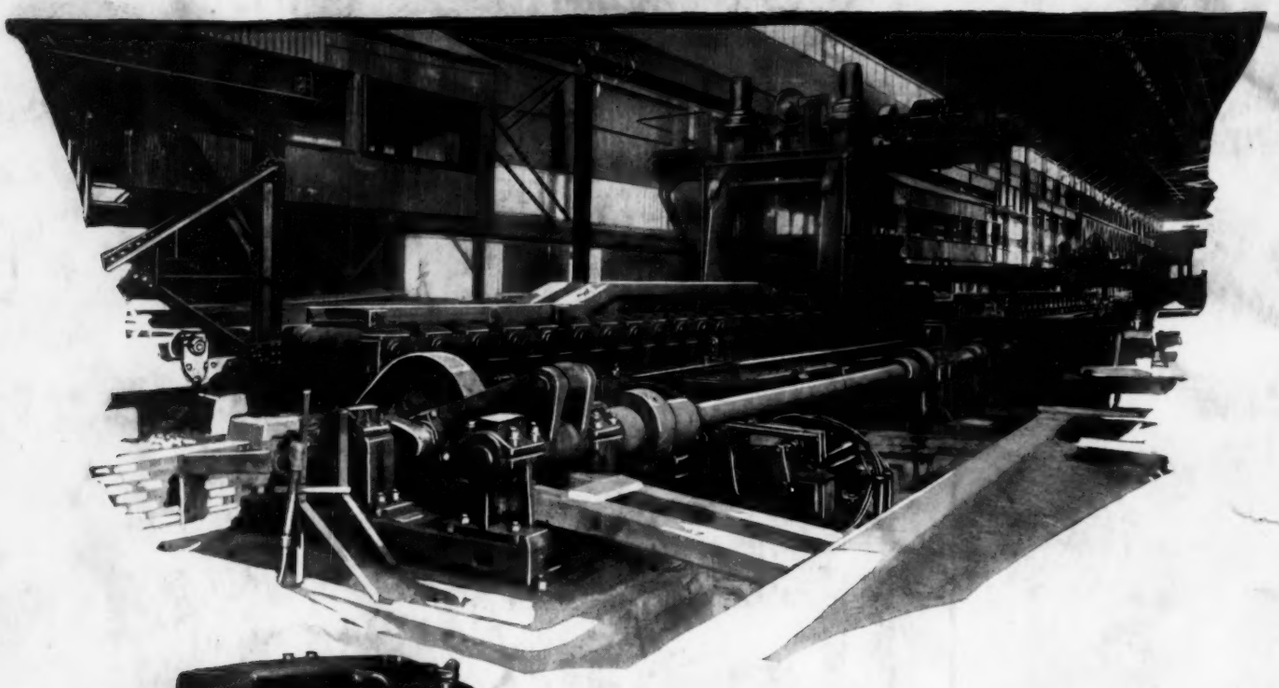
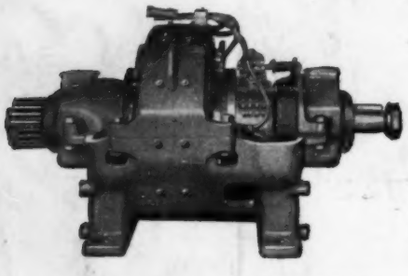


Standard Enclosed Frame DC Mill Motors, Type MD—range from 4 to 175 h.p., 230 and 550 volts.



Standard Open Frame DC Mill Motors, Type MDS—range from 6 to 210 h.p., 230 and 550 volts.

Right Motors for Steel Mills

Every machine in your mill, every foot of floor space and every employee must yield the maximum in order to meet the demands for increased production. One device or method will help at one point, another fills a further need; but electric power properly applied through G-E motors will help at all points.

G-E mill type DC motors are the right kind for driving live roll tables and screw downs—and are universally selected for other severe duties in the steel mill.

These motors are made to meet all steel mill requirements. They are reliable, have ample overload capacity, and high starting and maximum torques. Their design makes replacement and repair easy, while the small stored energy in their armature facilitates rapid reversals.

G-E engineers are ready to co-operate with you in solving your problems, and can select the proper drive from a large standard line of steel mill motors and control equipment which has been specially designed for each and every class of steel mill machinery. Write for Bulletin No. 48121.1A.

General Electric Company
Schenectady, N. Y.
Sales Offices in all Large Cities

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GENERAL ELECTRIC